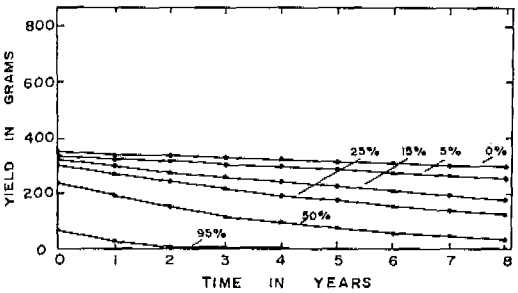

FIGURE 3.—Yearly yield from brook trout population with additional mortality imposed on the 0-age group. The number above each line is the percent decrease in survival of the 0-age group. For each line, the initial population size is 11,568 individuals in a stable age distribution.

figures the initial age structure is not stable with respect to the modified projection matrices used to calculate the 5%, 15%, . . . , 95% curves. The appropriate modification is to recalculate λ_1 and the stable age structure, for every percent decrease in survival. For example, when survival of the 0-age group is decreased by 95%, the stable vector is $S_1 =$ [10000, 70, 58, 24, 5] and $\lambda_1 = .41$. Then, the stable population is adjusted as before to 11,568 individuals at time zero. The projected yields thus obtained are plotted in Figure 3. It is now clear that the yields do not oscillate and are asymptotically decreasing towards zero.

When the initial age structure is unstable, the trout population oscillates. Therefore, the effect of additional mortality can be misinterpreted. However, oscillations are temporary; the population will reach a stable age structure and run towards extinction. Only changes in the birth or death rates that would set $\lambda_1 \geqslant 1$ could prevent such an outcome.

ACKNOWLEDGMENT

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Swimming Performance of Adult Sea Lamprey, *Petromyzon marinus*, in Relation to Weight and Temperature

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ABSTRACT

Distance (m) sea lampreys, *Petromyzon marinus*, swam increased with weight (2.4–106.9 g) but at a decreasing acceleration for a fixed velocity and temperature. Distance declined with increase in swimming speed between 20–60 cm/sec at a decreasing acceleration. The greatest distance was recorded for the largest lampreys at the lowest swimming speeds. Distance increased with temperature between 5–15 C. Performance of sea lampreys was less than that for teleosts which may be related to differences in their morphology.

Completion of the predaceous trophic phase in *Petromyzon marinus* is dependent on its ability to locate and successfully attack fishes. The importance of swimming in locating prey is uncertain. However, swimming performance does not appear to be an important factor in the actual attack as fish make no attempt to avoid sea lampreys (Lennon 1954; Farmer and Beamish 1973).

Preparatory to spawning, sea lampreys ascend tributary streams, sometimes for long distances (Bigelow and Schroeder 1958; Potter and Strahan 1968). Qualitative rates of upstream migration have been made for the landlocked *P. marinus* by Skidmore (1959) and Wigley (1959) and suggest low swimming speeds. Observations by Applegate (1950) and others indicate sea lampreys are facilitated in ascending fast flowing reaches by attaching to rocks and other objects with their oral disc, thus maintaining position between swimming surges.

In this study time and distance were used as a yardstick of continuous swimming performance and were measured for adult sea lampreys of different weight in relation to water velocity and temperature.

MATERIALS AND METHODS

Sea lampreys in the final stages of metamorphosis (Beamish and Potter 1972) were

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collected during the autumn of 1970 and 1971 by electrofishing from Shelter Valley Creek, a tributary of Lake Ontario.

Adult lampreys were maintained at 10 ± 1 C in 1200- and 2000-liter circular tanks supplied with aerated well water and exposed to a photoperiod of 16 hr. They were allowed to feed *ad libitum* on white suckers *Catostomus commersoni*, carp *Cyprinus carpio*, and rainbow trout *Salmo gairdneri* for at least 2 months before being used for experimentation.

Before sea lampreys were used in an experiment they were acclimated to a fixed temperature by a daily change of one degree and allowed at least 2 weeks at the desired temperature. Lampreys were deprived of food for 4 days before the start of an experiment to assure complete evacuation of the digestive tract. Oxygen content in holding tanks was kept at 90–100% of air saturation and ammonia N generally was below 0.1 mg/liter.

Swimming performance was determined in the chamber described in Farmer and Beamish (1969). Briefly, water is driven by a centrifugal pump into an expansion chamber in which are located a series of flow "straighteners," through a reduction cone, and into the portion of the chamber in which lampreys were forced to swim. Velocity profile in the swimming chamber was rectilinear and essentially constant. I discouraged lampreys from attaching to the inner surface of the swimming chamber by lining it with one layer of fine and one of coarse mesh screening.

Sea lampreys to be tested were placed in the chamber and water velocity steadily increased to the desired speed. Gentle prodding was used sometimes to induce lampreys to swim. The time a sea lamprey swam at a fixed velocity was used to calculate distance. When a sea lamprey was fatigued, it was forced against the end screen. Usually the onset of fatigue was obvious. The chamber water was continually exchanged with that from a well aerated reservoir. Dissolved oxygen in the swimming chamber did not fall below 90% of air saturation. After a test, the sea lamprey was removed, weighed and measured to the nearest 0.1 g and 1 mm, respectively.

The temperature range examined was 5–15 C. At each temperature performance was determined for velocities from 30–60 cm/sec. No fewer than 10 lampreys were used at each swimming speed and temperature. Weight and length of the 160 lampreys used ranged from 2.4–106.9 g and 12.3–14.8 cm, respectively.

RESULTS AND DISCUSSION

Swimming performance was not enhanced by training procedures such as those employed by Brett (1964) or Farmer and Beamish (1969). The length of time sea lampreys of different weight swam in relation to water velocity and temperature is represented by the equation:

$$\log Y = 2.9148 + 0.4975 \log X_1 + 0.0294 X_2 - 0.0380 X_3$$

where Y is time in seconds

X_1 is weight in g
X_2 is temperature in C
X_3 is swimming speed in cm/sec

The correlation coefficient R, for X_1, X_2, and X_3 was 0.837, significant at $P > 0.01$.

The time sea lampreys were able to swim steadily at a given speed and temperature increased approximately as the square root of their weight. As speed increased the logarithm of time a lamprey swam decreased at a rate of 0.0380, provided weight and temperature were held constant. Thus, for a given temperature, maximum time of swimming was recorded for the largest lampreys at the lowest speeds. The logarithm of time for a sea lamprey of a particular weight at a fixed speed increased with temperature at a rate of 0.0294. The influence of weight (length), swimming speed, and temperature on distance sea lampreys swam is presented in Fig. 1.

Quantitative measurements of the swimming performance of adult lampreys, irrespective of species, are particularly scarce, the observations of R. W. McCauley and J. F. Skidmore (personal communication) on swimming speeds of nonfeeding migrating *P. marinus* (38 cm) preparatory to spawning being a notable exception. They determined the maxi-

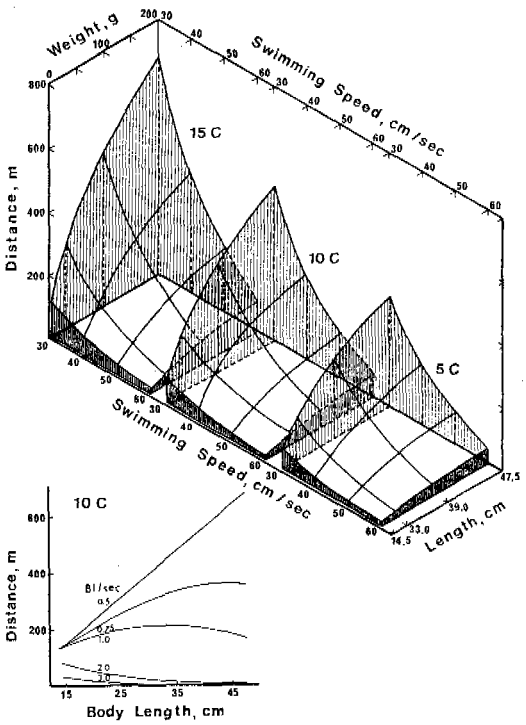

FIGURE 1.—Distance sea lampreys swam in relation to speed, body weight, and temperature. In the lower panel distance at different swimming speeds, expressed as body length (BL)/sec, is presented in relation to body length.

mum speed sea lampreys could sustain for a 1-min period at 2 and 15 C. The maximum sustained speed at 15 C was 35.5 cm/sec and that at 2 C, 23.0 cm/sec, equivalent to distances of 21.3 and 13.8 m, respectively. In the present study sea lampreys of similar size but still actively feeding were estimated from the equation to be able to swim for 315 m at 35.5 cm/sec and 15 C and for 250 m at 23.0 cm/sec and 2 C. Presumably at least part of this difference can be attributed to the influence of food deprivation and the spawning migration on the depletion of energy stores.

Large sea lampreys swam farther than small individuals at speeds under one body length (BL) per second (Fig. 1). However at swimming speeds above 1 BL/sec performance favors the smaller sea lampreys. This reduction in relative performance with increase in size of lamprey is in accord with the earlier observations of Brett (1965) on sockeye salmon, *Oncorhynchus nerka*, and Beamish (1970) on largemouth bass, *Micropterus salmoides*.

In teleosts the increase in performance continues to an optimum temperature and thereafter declines (Brett 1964, 1965; Beamish 1966, 1970). Performance of sea lampreys which was highest at 15 C was not determined above this temperature on account of the high mortality rate among the larger individuals.

Sea lampreys are poor swimmers in comparison with most species of teleosts. Sockeye salmon (18 cm) are able to sustain speeds of slightly over 70 cm/sec at 15 C for periods of at least 60 min (Brett 1964). Maximum sustained speeds (30 min) for largemouth bass of similar length varied from 30 cm/sec at 10 C to 52 cm/sec at 30 C (Beamish 1970). Sea lampreys of 18 cm were estimated to be able to sustain swimming speeds of about 1 cm/sec for 30 min at 15 C and less at 5 C. Further in a study on the swimming endurance of a number of marine teleosts (Beamish 1966), all were able to swim for longer periods at higher speeds than those found for sea lampreys.

Rates of upstream migration reported for sea lampreys corroborate the present observations on their poor performance. Where the mainstream flow is rapid, sea lampreys move upstream near the edges (Hardisty and Potter 1971) where they may be assisted by eddy currents. In the slow flowing regions of Cayuga Inlet, Wigley (1959) reported an average rate of upstream migration of under 5 cm/sec which was in accord with the observations of Skidmore (1959) for the same species in the Pancake River, a tributary of Lake Superior. The anadromous *Lampetra fluviatilis* appears to be a stronger swimmer and rates of over 100 cm/sec (2.51 BL/sec) have been reported by Abakumov (1956) during the initial stages of migration from the Gulf of Riga. During the later stages of migration rates decreased to 20–40 cm/sec.

A number of factors may contribute to the poor performance recorded by sea lampreys. The absence of a hydrostatic organ requires the expenditure of additional energy to maintain position in a column of water. Stability

in lampreys is reduced as a result of the absence of paired fins which in teleosts and elasmobranchs serve as hydroplanes. Because of poorly developed ventral and caudal fins posterior turbulence is probably higher than that in most anguilliform fishes. The reduced caudal fin would not appear well adapted for providing a propulsive thrust. Recent information on the active oxygen consumption of adult sea lampreys (Beamish 1973) suggests it is well within the range found for teleosts.

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Streptococcus sp. from Marine Fishes Along the Alabama and Northwest Florida Coast of the Gulf of Mexico[1]

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ABSTRACT

Fish kills in estuarine bays along the Florida and Alabama Gulf Coast were investigated in August and September 1972. Eight species of moribund fish were examined. A nonhemolytic, group B, type I_b *Streptococcus* sp. was isolated from over 90% of the fish examined. Parasites and toxicants were eliminated as possible causes of the kills.

Acute fish epizootics attributable to bacterial infections in estuarine areas are infrequent (Sinderman 1966). Most of the epizootics induced by bacteria in the marine environment have been attributed to *Vibrio anguillarum* (Rucker 1959; Sinderman 1966) and

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