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OSMOREGULATION IN THE BROOK TROUT, SALVELINUS FONTINALIS

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Brook trout (Salvelinus fontinalis) often migrate from freshwater to seawater when given free access to the ocean. Movement into comparatively rich marine systems can result in growth rates that are four to five times that of cohorts remaining in freshwater. This fact, in combination with high return rates of brook trout to their parent stream, makes this a potentially valuable species for sea ranching, fish farming and enhancement programs. However, several questions concerning the migratory tendency of brook trout remain unanswered. One important question is the osmoregulatory ability of brook trout, specifically the roles of size, age and photoperiod in determining their ability to osmoregulate in seawater. Current work in our laboratory is designed to answer this and other questions related to salmonid osmoregulation and smoltification.

In order to determine whether size, age and/or photoperiod are important in the osmoregulatory ability of brook trout, we separated several thousand fry of a controlled genetic stock into fast and slow growing groups using feeding rate to control growth. We further divided the fish into two photoperiods; one is "normal" daylength, decreasing in fall and increasing in the spring, while the second is 3 months out of phase with the normal photoperiod. Every 6 weeks fish from each group are acclimated to seawater using a gradual procedure of one week at 10 o/oo, another week at 20 o/oo and then exposure to 30-31 o/oo seawater. Growth and survival of brook trout in seawater is monitored for a least 20 days. To determine the osmoregulatory ability of these fish, plasma levels of Na^+, Cl^-, K^+, Mg^{++} and total osmotic concentration are measured at discrete intervals. Gill Na^+-K^+ ATPase, an enzyme responsible for blood ion homeostasis, is measured in animals exposed to seawater and in a freshwater control group. The circulating levels of the hormone thyroxine is also being measured to determine its effect on osmoregulatory ability and seawater survival.

Experiments conducted over the past year and a half have shown a strong dependence of seawater survival and hypoosmoregulatory ability on body size. Larger, faster growing fish show greater salinity tolerance than smaller, slower growing fish (Fig. 1). Body size can explain up to 79% of the variation in seawater survival time of brook trout.

Photoperiod exerts its strongest influence on hypoosmoregulatory ability through the maturation cycle. During declining photoperiod a period of normal spawning for brook trout, mature males exhibit poor salinity tolerance relative to immature males and mature and immature females (Fig. 3). Mature males also demonstrate poorer abilities to regulate plasma chloride, magnesium and total osmotic concentration.

In smolting salmonids, increasing photoperiods result in a myriad of physiological changes, perhaps mediated by thyroxine, which facilitate hypoosmoregulation. No dramatic increases in salinity tolerance occur in brook trout under increasing photoperiods. However, Figure 3 demonstrates that a photoperiod controlled annual cycle in thyroxine does occur, declining in the falling and rising to a springime maximum in March. The magnitude of springtime increases in thyroxine levels in the brook trout do not equal those shown to occur in smolting salmonids. An increase in gill NA^{+}-K^{+} ATPase activity, which might indicate preparation for seawater entry mediated by thyroxine, did not occur and thus the physiological significance of the thyroxine cycle remains unclear.

In the coming months we will be defining our model of hypoosmoregulation in brook trout to include variables such as gonadosomatic index, growth rates and condition factors. With this added information we should obtain even greater accuracy in predicting salinity tolerance and discerning the underlying physiological mechanisms that allow brook trout to osmoregulate in seawater.

Physiological constraints discovered under laboratory conditions may be important in nature to varying degrees. In 1982 we examined natural populations of brook trout in order to determine whether physiological constraints affect anadromy and hypoosmoregulation. Field studies were conducted between naturally anadromous (Rivière à la Truite) and non-anadromous (Matamek River) populations of brook trout so as to determine temporal, spatial, size and age related changes in thyroxine, gill Na^{+}-K^{+} ATPase and hypoosmoregulatory ability. Three fyke nets were set in Rivière à la Truite and checked daily from early June to mid-September. In the Matamek River two fyke nets were set between the 2nd and 3rd Falls and checked three times a week throughout the summer. Some trout were seined from the Matamek Estuary during June, in a cooperative effort with the smolt project. The mouth of the Moisie River was seined twice monthly at two sites; one at the mouth of the river and one approximately 1 km upstream.

Upon capture, all fish except lamprey and eel were anesthetized and fork lengths were measured to the nearest cm. All fish, except lamprey and eel, were given a fin clip and released downstream of the capture net. A small representative sample of brook trout, salmon parr, and lake chub were taken and either were sacrificed immediately, or taken back to the station and placed in 32 o/oo sea water for 24 hours (e.g., seawater challenge), then sacrified. From all sacrificed fish, fork length, weight, and silvering were recorded; blood was taken for subsequent analysis of thyroxine and osmolarity, and three to four gill arches were removed from each fish and frozen for determination of gill Na^{+}-K^{+} ATPase activity.

Brook trout, salmon, longnose sucker, white sucker, lake chub and lamprey all left Rivière à la Truite in significant numbers just after peak water levels (Fig. 4). Emigration of all species was protracted over a two month period until late July. Several peaks in brook trout movements occurred, often coinciding with increased water levels due to rainfall. The first half of the migratory period contained a significantly ($P < 0.05$), 2x2 contingency table) greater proportion of larger (>16 cm) brook trout than the latter half.

Seawater challenge experiments indicate that both size and location (i.e., proximity to saline waters) are important in determining hypoosmoregulatory ability under natural conditions. Fish taken from Rivière à la Truite showed moderate ability to maintain blood ion concentration after 24 hours in seawater (Table 1) with slight increases in ability with increased size. Brook trout from the downstream site at the Moisie River estuary performed better than brook trout from the upstream estuary site and Rivière à la Truite (Table 1). Similarly, brook trout from the Matamek River estuary performed better under hypersaline conditions than fish from the Matamek River.

Thyroxine and gill Na^+-K^+ ATPase determinations are complete and await further analysis. Preliminary results indicate that gill Na^+-K^+ ATPase in estuarine brook trout show elevated activity (Table 1). These results support our observations of increased hypoosmoregulatory ability of estuarine fish, and suggest that behavioral changes act in concert with physiological constraints of size to determine hypoosmoregulatory ability.

ACKNOWLEDGEMENTS

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Table 1. Size, plasma osmolarity and gill Na^{+}-K^{+} ATPase of brook trout after 24 hours in seawater. Fish from Rivière à la Truite were sampled June 9 and 25 during peak emigration. Fish from the estuary were captured on several occasions from July 2 to August 31.

	N	Size (cm)		Osmolarity (Osm/L)	Gill Na^{+}-K^{+} ATPase (μ MPi mg $Prot^{-1} \cdot hr^{-1}$)
		Range	Mean	Mean (± sem)	Mean (± sem)
Rivière à la Truite	9	9.5-19.5	13.2	454 (11.5)	-
Moisie River Estuary (upstream)	10	12.3-18.4	14.1	496 (5.2)	5.9 (0.8)
Moisie River Estuary (downstream)	9	15.2-20.5	18.1	395 (6.7)	9.4 (0.9)

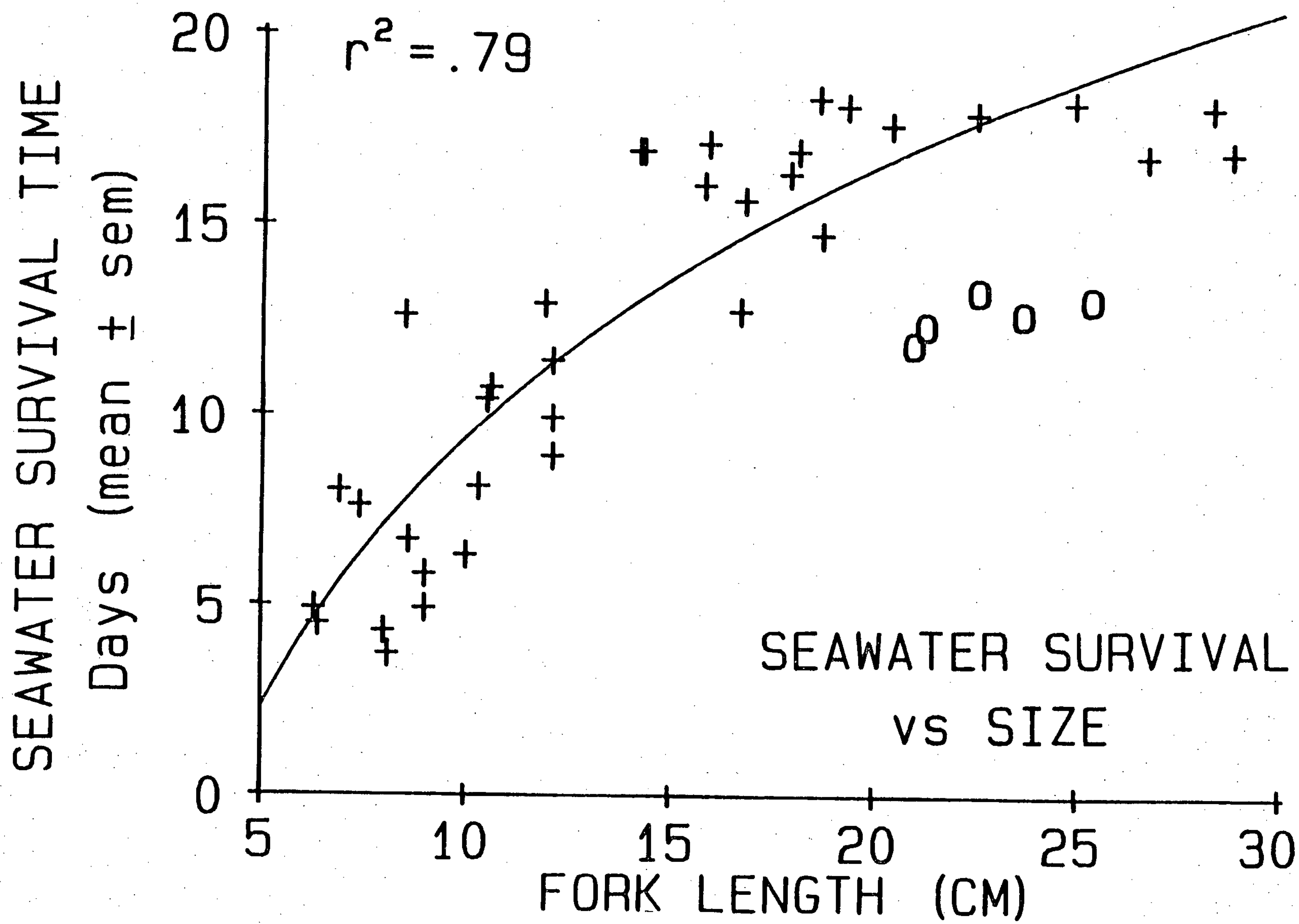
Figure Legends

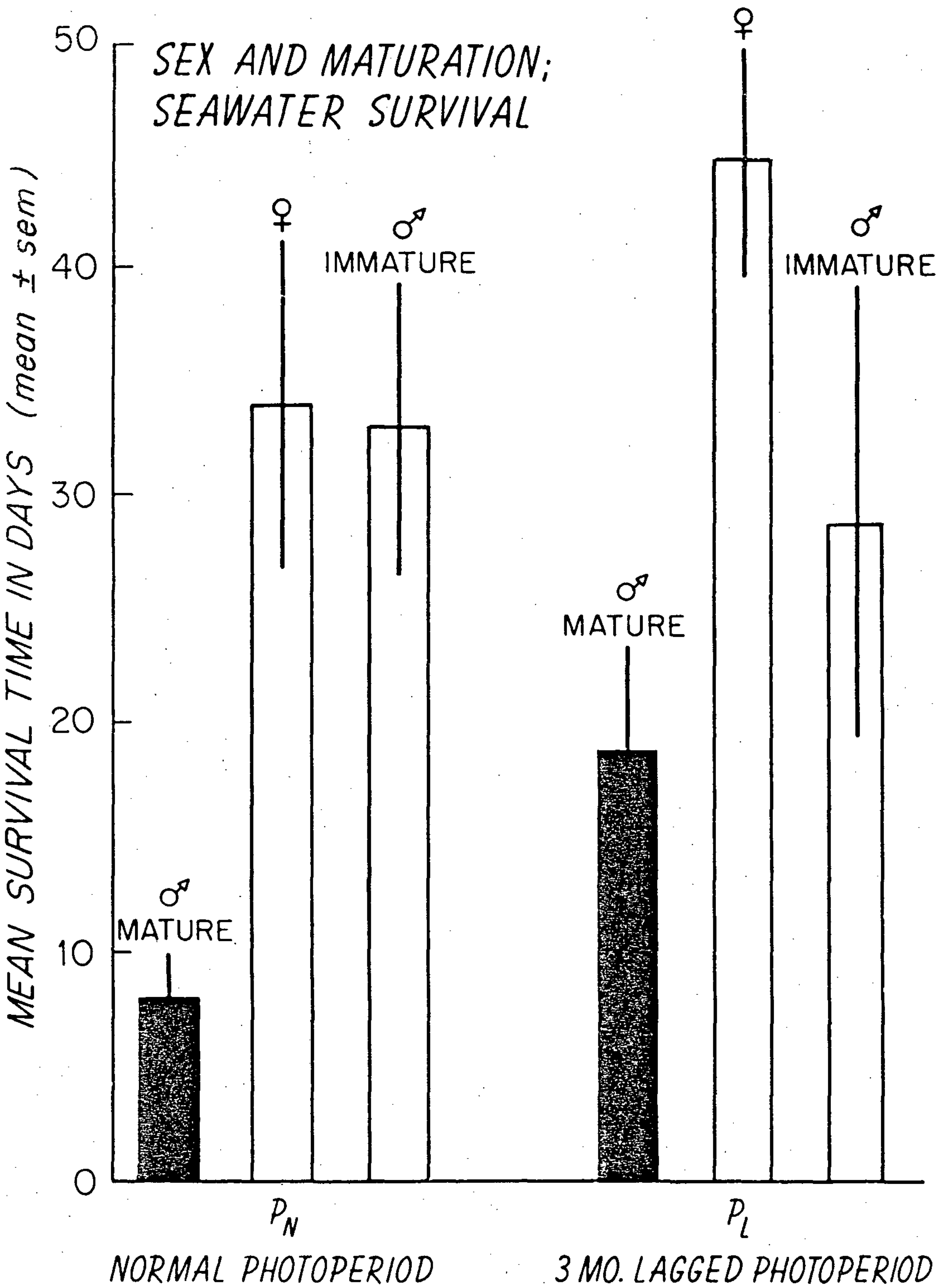
Figure 1. Mean seawater survival time versus mean fork length of brook trout exposed to 32 ppt seawater. Open circles represent experiment performed in autumn and winter, and which contained significant numbers of mature males.

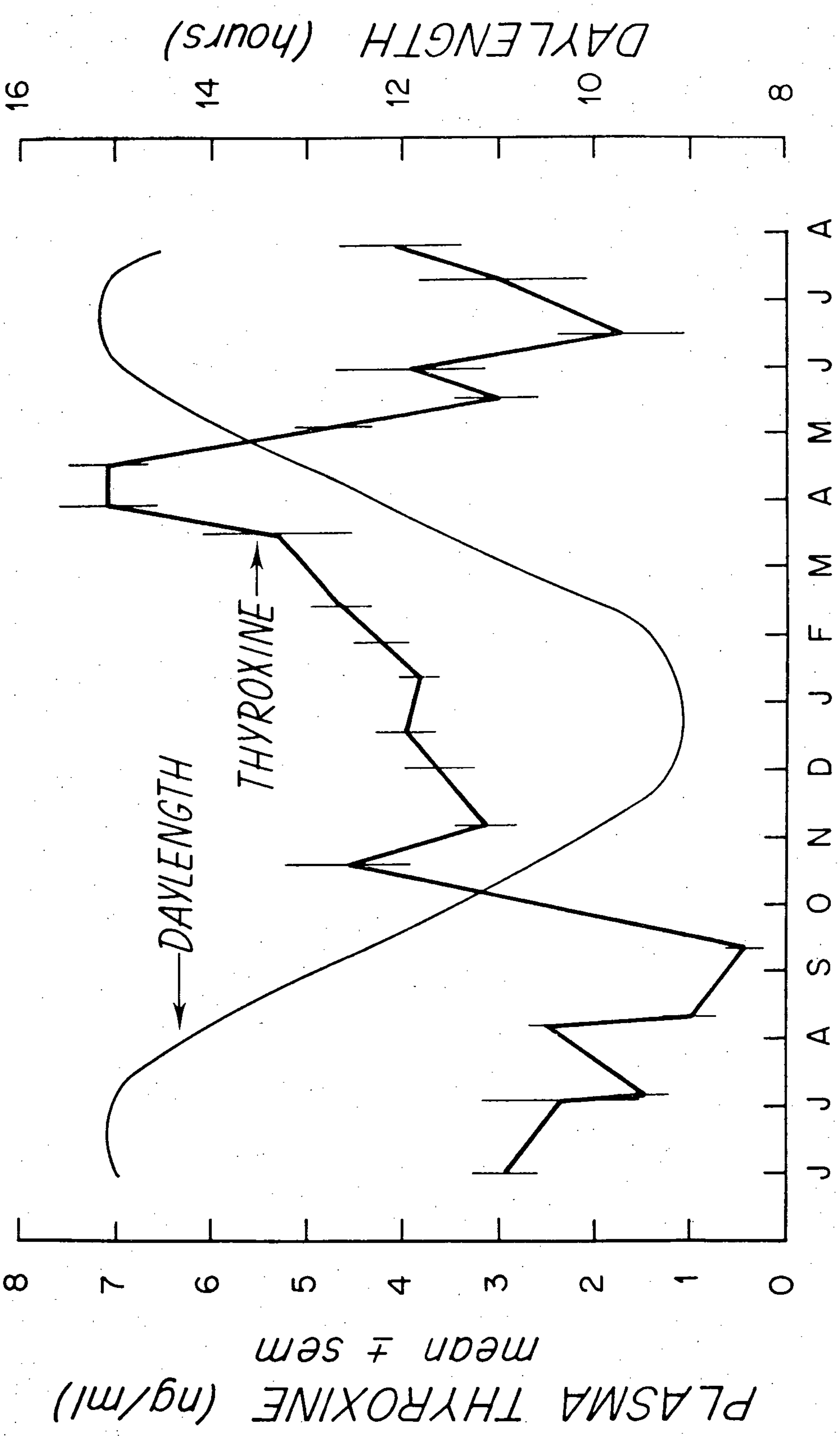
Figure 2. Mean seawater survival time of mature males, immature males and females. Normal photoperiod (P_N) experiment was conducted under autumn day length conditions when normal spawning occurred. Lagged photoperiod (P_L) experiment occurred under summer day length conditions.

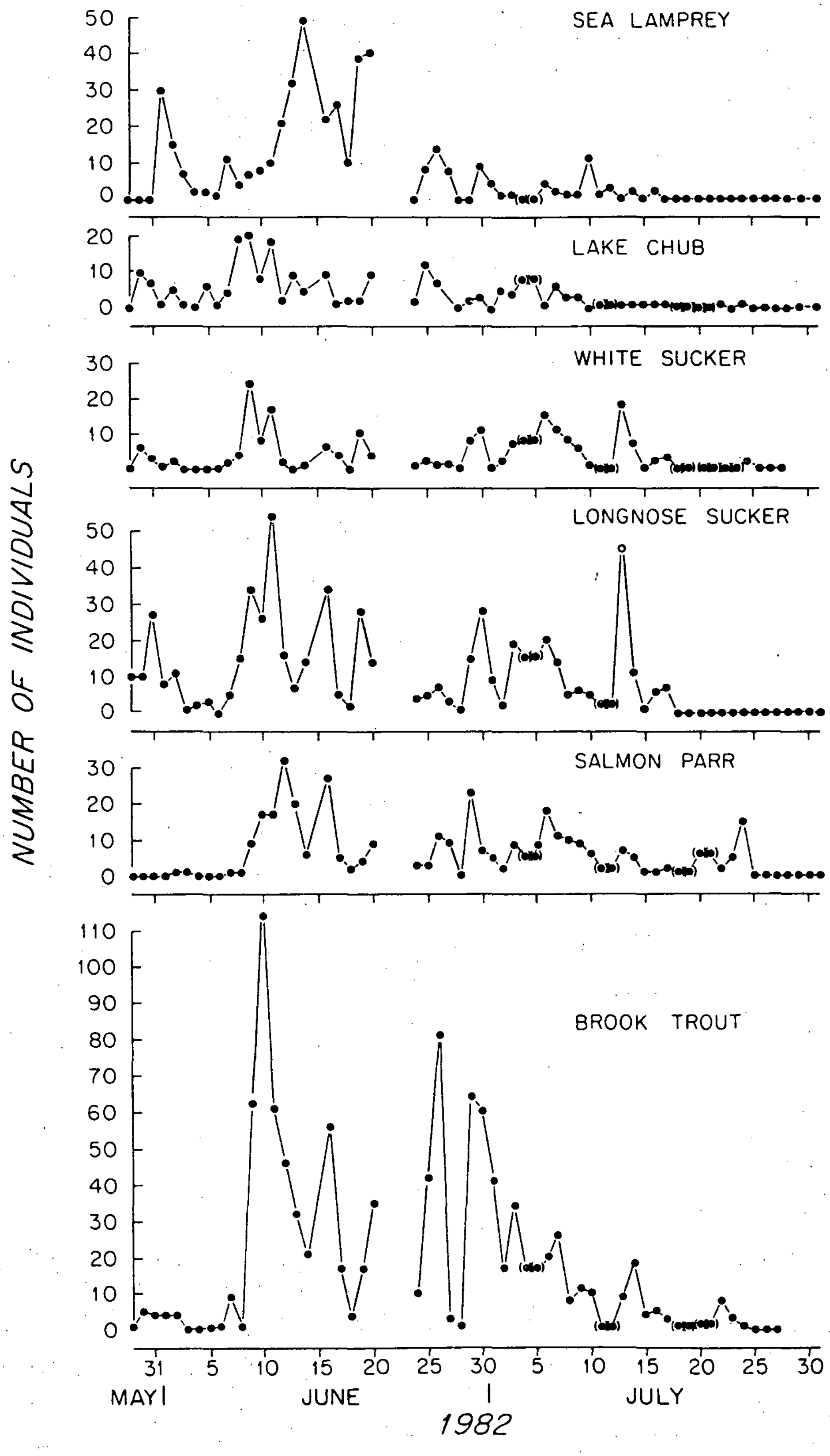
Figure 3. Plasma thyroxine levels and day length as a function of time.

Figure 4. Daily capture of fishes in upstream facing net at mouth of Rivière à la Truite in 1982.


SEAWATER SURVIVAL TIME
Days (mean ± sem)
20
15
10
5
0
5
10
15
20
25
30
FORK LENGTH (CM)
r² = .79
SEAWATER SURVIVAL
vs SIZE


SEX AND MATURATION;
SEAWATER SURVIVAL
MEAN SURVIVAL TIME IN DAYS (mean ± sem)
50
40
30
20
10
0
♂ MATURE
♀
♂ IMMATURE
♂ MATURE
♀
♂ IMMATURE
P_N
NORMAL PHOTOPERIOD
P_L
3 MO. LAGGED PHOTOPERIOD


PLASMA THYROXINE (ng/ml)
mean ± sem
DAYLENGTH (hours)
0 1 2 3 4 5 6 7 8
8 10 12 14 16
J J A S O N D J F M A M J J A
DAYLENGTH
THYROXINE


SEA LAMPREY
LAKE CHUB
WHITE SUCKER
LONGNOSE SUCKER
SALMON PARR
BROOK TROUT
NUMBER OF INDIVIDUALS
31
5
10
15
20
25
30
5
10
15
20
25
30
MAY
JUNE
JULY
1982