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ANALYSIS OF FRESHWATER INFLOW EFFECTS  
ON METABOLIC STRESSES OF FISH IN  
CORPUS CHRISTI, SAN ANTONIO,  
AND MATAGORDA BAYS

Final Report to  
Texas Water Development Board for  
TWDB Contract No. 14-60020  
(IAC-7677-0632)

(with Appended Data)

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Gentlemen:

With great pleasure, I am submitting herewith the final report, "Analysis of Freshwater Inflow Effects on Metabolic Stresses of Fishes in Corpus Christi, San Antonio, and Matagorda Bays," supported under contract IAC-7677-0632.

All of us involved in this study gratefully acknowledge the support of TWDB.

The results are quite straightforward and provide a useful addition to the knowledge of seasonal characteristics of south Texas waters and their fishes. Further, the work used in this report has suggested several new lines of research endeavors that are to be the subjects of a Master's thesis and a Ph.D. dissertation.

Prefixing the report is an "executive summary" that includes the general rationales, the results in abbreviated form, and a recommendation for extended studies to include other coastal fishes using the new techniques developed in this study. The technique of assessing salinity optima by measuring maximum sustained swimming rates may turn out to be an inexpensive, rapid and easily applicable technique.

Work on this project has been a rewarding experience in terms of cooperation among all those involved at administrative, research and technological levels.

Respectfully submitted,

*Donald E. Wohlschlag*  
Donald E. Wohlschlag  
Professor

DEW:jp

Encl: 25 copies



FINAL REPORT

to

Texas Water Development Board

for

TWDB Contract No. 14-60020  
(IAC-7677-0632)

ANALYSIS OF FRESHWATER INFLOW EFFECTS ON METABOLIC  
STRESSES OF FISH IN CORPUS CHRISTI, SAN  
ANTONIO, AND MATAGORDA BAYS

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## EXECUTIVE SUMMARY

### General Considerations

This study involves the rationales for: (1) investigation of freshwater inflow effects on South Texas estuaries and bays; (2) utilization of fish as indicators for optimal effects of these inflows; and (3) the use of metabolic and swimming rate techniques for the assessment of inflow effects independently of fishery and pollution effects.

The purpose of this study is to evaluate stresses related to freshwater influxes on the coastal subadult to adult spotted sea-trout or "speckled trout" (Cynoscion nebulosus), which is highly valued for food and recreation.

The balance among freshwater inflows, evaporation, and seawater influxes directly determine the salinities of the coastal bays and estuaries, which biological experience indicates function best at less than seawater salinities (35 parts per thousand, ppt). Only fresh waters (zero ppt salinity) via streams and rivers can naturally maintain estuaries and bays at less than seawater salinities and at maximum biological productivity.

What is the optimal salinity - or salinity regime - and how much freshwater inflow is necessary to maintain optimal salinity regimes for any given species (or for the entire ecosystem) are questions of utmost importance for maintenance of bay and estuarine productivity. That salinity is a natural stress whose minimal effects can be identified for the spotted sea trout is the basis of this study.

The basis of indefinite survival of a species like the spotted sea trout is that it be considered as a successful integrator that can optimize all the living and non-living environmental factors, many of which can be occasionally stressful.

For swimming fishes, as well as for distance runners, race-horses, etc., maximum sustained performance depends upon optimum internal and external environmental circumstances. At a maximum sustained performance level, metabolism as measured by oxygen consumption rate is also maximal. A normal organism at zero activity under optimal environmental conditions has a standard (maintenance, or basal) metabolic level that is the lowest level for short term survival without energy expenditures for growth, foraging, assimilation, reproduction and other required functions. If an organism survives at all below the standard metabolic level, it will lose weight, show some degree of morbidity, and not be able to carry out completely these functions.

At some energy level between the maximum sustained and the standard (maintenance) metabolic levels is the level of routine metabolism that is high enough to account for these normal functions. The difference between the standard and the routine metabolic rates is the scope for routine activity. Similarly the difference between the standard and the maximum sustained swimming metabolic rates is the scope for maximum activity.

Either of these metabolic scopes for activity is a measure of the well being of a fish, independently of extraneous stresses such as those from fisheries. The maximum scope is especially sensitive to general, sublethal environmental stresses.

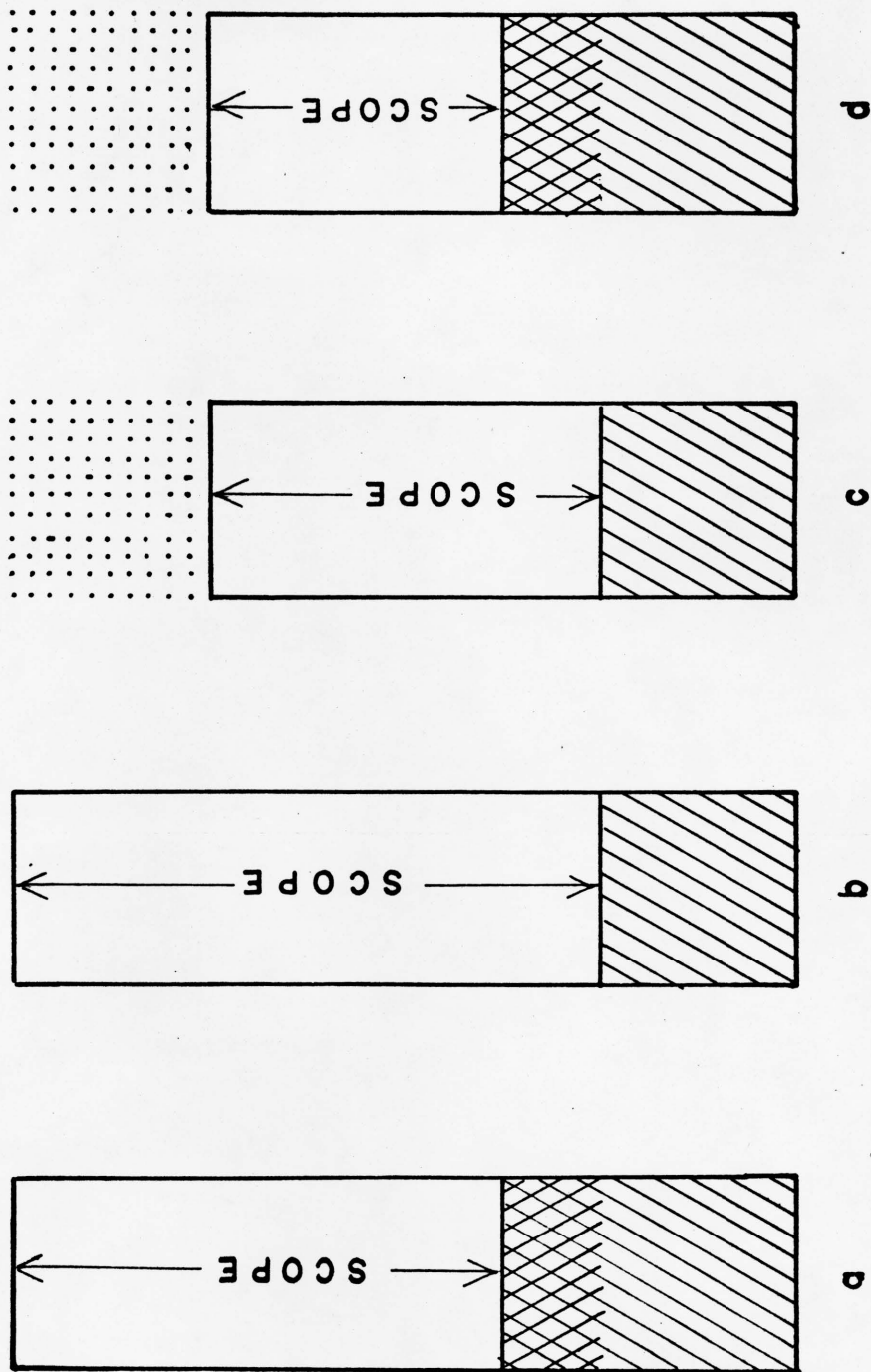
The idea of scope and its interpretations are shown diagrammatically in the figure, where hatched and cross-hatched portions are standard metabolic levels. At optimal conditions the maximum scope is given in (b). When a natural stress like salinity is applied at higher or lower than optimal levels, the maximum scope must decrease because extra maintenance work is required for salt regulation, i.e., the standard or maintenance level must be raised, thus reducing the scope as in (a) and (d) in the figure. (If a stress like a chemical pollutant is not natural, it is likely that the body's biochemical machinery will ultimately break down, lower standard metabolism, and result in morbidity or death).

When less than optimal conditions prevail among natural stresses like salinity, or with sublethal stresses like pollutants, the maximum metabolic levels are depressed as in (d). A possibility of reduced activity and scope without a change in standard level is shown in (c). In all cases the routine scope and the routine metabolic level is less than for the maximum scope and maximum metabolic level.

Scope can thus only decrease under stress either by reducing the activity metabolic level, by increasing the standard level, or by both.

NORMAL, FASTED FISH

SCOPE FOR MAXIMUM SUSTAINED SWIMMING





## Results

- In all cases of this study on the spotted sea trout, both the scope at maximum sustained swimming levels and the scope at the routine levels were the greatest at about 20 ppt salinity for fish in seawaters of various concentrations or dilutions.
- Salinity is optimal at about 20 ppt for summer temperatures of 28°C and for winter temperatures of 15°C. There appear to be no temperature shifts in salinity effects.
- At about 10 ppt and at about 45 ppt, the standard (maintenance) requirements are about double those at 20 ppt.
- At about 10 ppt and at somewhat less than 45 ppt, the routine metabolic levels are about high enough (double the standard rates) to allow for minimal foraging, assimilation and growth.
- From about 10 ppt to 45 ppt in natural coastal waters is the normal range for the occurrence of the spotted sea trout with most catches usually in waters from about 15-35 ppt.
- Studies of routine and standard metabolic rates at selected temperatures from 15°C - 25°C and selected salinities from 10 - 32 ppt for waters variously from Nueces, San Antonio and Lavaca (Matagorda) Bays revealed that these waters in 1976 caused no appreciable decrease in scope values that could be construed to result from sublethal pollution.
- In summer of 1975, but not 1976, the Nueces Bay waters caused an increase in standard metabolism, presumably caused by an unidentified sublethal stress.
- In autumn 1976, the spotted sea trout were in a starved condition that was progressively worse for the larger fish. At this

time both the standard and routine metabolic determinations at 35 and 45 ppt were depressed. The data suggest that, at given feeding levels, adequate scope for maintenance, and possibly for weight gains, would be likely only at less than 35 ppt.

→ In experiments at maximum sustained speeds for an hour or more, the speeds themselves are maximal at an optimum salinity of about 20 ppt for the spotted sea trout. It is suggested that maximum sustained speeds alone could be used for the identification of an optimal salinity level. (Routine speeds are not always directly related to optimal salinity).

#### Recommendations

→ It is recommended that both the maximum metabolic scope and the maximum sustained swimming speed methods of identifying the optimal salinity level be extended to other selected coastal fishes of importance in South Texas waters.

## INTRODUCTION

The purpose of this study is to evaluate quantitatively the relative importance of freshwater influxes on the metabolic responses of the spotted seatrout, Cynoscion nebulosus. This species is important to recreational and commercial interests along the south Texas coastal, bay and estuarine systems.

The rationale of the evaluation in this study, which was examined in a preliminary pilot study during July and August 1975, indicated that respiratory metabolism responded directly to salinity levels of both seawater and waters from Nueces Bay, a secondary bay adjacent to primary Corpus Christi Bay. The measurements that are pertinent include respiratory metabolic responses at standard, or maintenance, levels, active metabolism and swimming rate; and either "scope for routine swimming activity" or "scope for maximum sustained swimming activity" as elucidated by Fry (1947). Scope is the difference between active metabolic rates and standard (maintenance) rates at given environmental conditions. Original data on temperature optimization studies by Fry indicated clearly that "scope" was maximal at optimal temperatures, when scope was defined as the difference between active and standard, or maintenance, metabolic levels. Both theoretical and practical studies have indicated that with a given energy input any biological system under stress results in a system with reduced energy output when compared to a system that is unstressed and optimal.

Since Fry's (1947) study on metabolic scope and its maximization at optimal temperatures, numerous authors, including Fry (1957, 1971), have extended the concept of metabolic scope to various species and environmental circumstances. Brett (1958,

1964, 1965, 1971) and Brett, et al. (1969) have extended the concept to actively swimming salmon over a variety of environmental and feeding conditions. More recently Webb (1975) has reviewed several important features of hydrodynamics and energetics of swimming fish that are important for the interpretation of maximum scope at various stresses.

For Texas Gulf fishes, Wohlschlag and Cameron (1967) showed that a very low sublethal pollution level would tend to depress total metabolism much more at temperature extremes than at optimal temperatures. Wohlschlag, et al. (1968) demonstrated the nature of pinfish metabolism at routine and standard metabolic levels. Also, for the pinfish, Kloth and Wohlschlag (1972) noted that the swimming velocities tended to decline with increasing salinity, while very insignificant, sublethal pollution levels tended to depress total metabolism. A series of detailed studies of the Gulf coastal striped mullet tended to follow the same stress-metabolism patterns with respect to salinity, temperature, and water quality variations.

In field studies, throughout the year with pronounced seasonal changes in metabolism, the levels of total metabolism for mullet in water at 30-35 ppt salinity were always higher than in more brackish waters from San Antonio to Baffin Bays (Wohlschlag and Moore, ms.). The energy requirements to meet environmental stresses that result in increasing the maintenance (standard metabolism) requirements are considerable (Cech and Wohlschlag 1973, ms.). The scope for activity of the mullet also appears to be depressed under the slight pollutional stresses throughout the year in Galveston Bay (Wohlschlag, et al. ms.). Late summer stresses also appeared to



depress metabolism in Galveston Bay and to depress growth rates as well, presumably during the prolonged mid-to-late summer thermal stress (Cech and Wohlschlag, 1975). Nordlie and Leffler (1975) and Collins (MA thesis, Univ. Texas) note that the mullet isosmotic point is about 11 ppt, the point of minimal standard metabolism. There is a slight metabolic increase in less saline waters and a doubling of standard metabolism at about 45 ppt for these mullet.

In the preliminary 1975 July-August investigation, "A Pilot Study to Analyze Effects of Freshwater Inflows and Metabolic Stresses for Important Fish Species in Corpus Christi Bay, Texas," we have shown that the routine scope--the difference in metabolism between routine and standard levels--is optimal at a salinity of about 20 ppt. For seawater, the scope drops rapidly below and above this optimum. In the same pilot study, both the standard and routine metabolic levels of fish in Nueces Bay waters at 15 and 25 ppt were elevated to the extent that there was a strong implication of sublethal stresses not present in various concentrations of sea water. Presumably it would be impossible to increase the maximum energy output by increasing sustained maximum swimming rates, since these rates have an upper limit determined by the biological-biochemical systems under aerobic conditions and at specified temperature and salinity regimes.

It is therefore reasonable to predict that in all natural or man-induced stress situations at sublethal levels, the scope for aerobic activity must necessarily decrease by (1) raising the maintenance (standard) metabolism, (2) reducing the active metabolic level, or (3) by simultaneously increasing the standard



and reducing the active levels. For the spotted seatrout with a rather clearcut summertime 28°C optimal routine scope at about 20 ppt seawater salinity, the immediate questions arose as to the practical utility of extending this study through the remainder of the year at other salinities and temperatures, along with other variable, but unknown, seasonally changing ecological situations pertinent to the spotted seatrout. The seasonally extended evaluation of scope for routine activity is thus one of the major aims of this study.

The second major aim of the study is to draw some inferences about effects of waters in Nueces, San Antonio, and Lavaca Bays on metabolic scope at the routine level in order to ascertain whether any of these waters might have adverse stress effects on the scope that might be confused with freshwater influx effects.

The third major aim is (a) to evaluate with the new Blazka chamber metabolic scope at maximum sustained swimming speeds for the assessment of freshwater influx effects, and (b) to evaluate the maximum sustained swimming rates themselves at different salinities.

## MATERIALS AND METHODS

### General

Since this study followed essentially the procedures detailed in the pilot project, only the essentials of the operations will be given when procedures are identical. New or modified procedures will be given in more detail. Fry (1971) gives an overview of these and related techniques.

### Fish and Acclimation

The spotted seatrout, Cynoscion nebulosus, were obtained from various local sources by using live shrimp baited hook-and-line techniques. In October fish were taken from the Barney Davis Power Plant cooling pond, and later in the year from the intake canal off Laguna Madre. During winter and later they were obtained from near the Lydia Ann Channel near Port Aransas. Several small winter collections were made at the Rockport boat basin.

Fish were transported to the laboratory as soon as possible and held in large circular tanks at temperatures and salinities corresponding to the natural source waters. Acclimation was carried out in the experimental temperature controlled aquaria with 24-48 hour acclimation to temperature and salinities that initially were near ambient conditions at the source of waters. For major salinity changes of 5-10 ppt and temperature changes of 5°C, about 2-3 additional days were allowed for acclimation.

It is most important to note that the metabolic rate determinations were always made in the same waters in which fish were acclimated. Control was to  $\pm 0.1^{\circ}\text{C}$ .

Salinities of the laboratory seawater supply were adjusted to lower levels by adding deionized water or to higher levels by

the addition of sea salts. Control was maintained to about  $\pm 0.1$  ppt.

Determination of Respiratory Metabolism at  
Routine and Standard Levels

The techniques for measuring routine metabolism follow those of the pilot project as described and evaluated by Wohlschlag and Juliano (1959), Wohlschlag and Cameron (1967), Wohlschlag, et al. (1968) and Wohlschlag and Cech (1970).

Acclimated fish were placed in a 42.12 liter clear plastic circular (annular) metabolism chamber that could be rotated at variable speeds by a constant torque motor mechanism from which the chamber was suspended. The swimming track was 2 m per revolution. The entire chamber was immersed in the acclimation aquarium. With a minimum of handling each experimental fish was introduced into the chamber through a sealable hatch. Water samples for oxygen analysis were withdrawn through a small outlet tube from the chamber; replacement water was added through an inlet tube attached to a funnel.

Just as soon as the fish had become "adjusted" to the chamber, it was rotated at whatever speed the fish would swim consistently, the revolution counter reading was noted and counts were recorded for the usual 15-min intervals between removal of water samples for  $O_2$  analysis. For very small fish, the time intervals between  $O_2$  analysis were as long as 30 min. Ordinarily there were the initial and three additional equally spaced intervals at which the  $O_2$  level in the chamber was determined. With chamber  $O_2$  levels corrected for water withdrawn and added, a simple regression of the decline in  $O_2$  against time provided the value for rate of

oxygen consumption in  $\text{mg hr}^{-1}$ . At the termination of the run data on fish length, weight and sex were recorded.

Oxygen measurements were by means of a Radiometer PHM-71 acid-base analyzer and an E-5046 oxygen electrode with an appropriately thermostated system. Initial  $\text{O}_2$  levels and acclimation regimes were near saturation; levels were no lower than about 65% saturation at the termination of individual experiments at the higher temperatures with the largest, most active fish. The rate of  $\text{O}_2$  consumption as  $\text{mg O}_2 \text{ hr}^{-1}$  and as  $\text{mg O}_2 \text{ kg}^{-1} \text{ hr}^{-1}$  was calculated for each fish and tabulated with temperature, salinity, body weight and length, and swimming velocity ( $\text{cm sec}^{-1}$  and body lengths  $\text{sec}^{-1}$ ). The protocol for each experimental set of about 10 fish at a given salinity and/or temperature is given later under separate headings that pertain to experiments with the various bay and sea waters.

Except for portions of the Blazka respirometer experiments described below, the oxygen consumption rates may be linearly related to the several dependent variables as

$$\hat{Y} = a + b_w X_w + b_s X_s + b_v X_v$$

where

$\hat{Y}$  is the expected log  $\text{mg O}_2$  consumed per hour,

$a$  is a constant,

$b_w$  is a partial regression coefficient of the increase in  $\hat{Y}$  per unit increase in log weight at a constant salinity and swimming velocity,

$X_w$  is the log weight in grams,



$b_s$  is the partial regression coefficient of the increase or decrease in  $\hat{Y}$  per unit change in ppt salinity at a constant weight and swimming velocity,

$X_s$  is the salinity in ppt,

$b_v$  is the partial regression coefficient of the increase in  $\hat{Y}$  per unit increase in swimming velocity at constant weight and salinity, and

$X_v$  is the swimming velocity in fish lengths as  $\text{cm sec}^{-1}$ .

If temperature  $X_t$  was a dependent variable with a partial regression coefficient  $b_t$ , the term  $b_t X_t$  was added to the above equation. The linear first-order multiple regression procedure follows that of Wohlschlag and Juliano (1959), Wohlschlag and Cameron (1967), Wohlschlag et al. (1968) and Wohlschlag and Cech (1970). The techniques are given in most statistical manuals, e.g., Snedecor and Cochran (1967).

The combinations of data used in various regression calculations are given in the appropriate tables in the section on results. Initially the regressions were calculated by use of two sets of about 10 experiments each that were at adjacent salinity intervals, so that about 20 experiments would yield an estimate of the oxygen consumption rate over a small salinity range at a given temperature and in other cases over a small temperature range at a given salinity. Various other regressions were calculated to cover more data over larger temperature and salinity ranges.

Standard respiratory metabolic rates were extrapolated by using the original data sets of about 10 determinations plotted



as  $\log O_2$  consumption  $kg^{-1}hr^{-1}$  against swimming velocity  $X_v$ , so that the lowest of the individual rates could be extrapolated to  $X_v = 0$ . This method (Brett, 1964) has been checked by Moore (1976) for the striped mullet and found to be in good agreement with direct determinations of the standard rate with minimally quiescent fish. One or more of the calculated multiple regressions pertinent to the subset data range was/were used to extrapolate from the lowest data point back to  $X_v = 0$ , provided the regression  $\hat{Y}$  (on a per kilogram basis) calculated with the subset average  $\log$  wts, swimming velocities, salinities and temperature passed through or very near the subset  $\bar{Y} kg^{-1}$  and  $\bar{X}_v$ . If this regression passed near these means, it should be noted that its  $X_v = 0$  value would be considerably higher than the  $X_v = 0$  value plotted from a line parallel but through the minimum value(s). This is the same procedure utilized in the pilot study for the estimation of the standard rates. It should be noted here that another thesis research project on spotted seatrout metabolism has yielded minimal standard metabolism rates (over 24-hr controlled conditions) that are remarkably similar to those of this study. Hopefully these unpublished results will be available in published form within a year.

#### Metabolism at Maximum Activity

The Blazka "swimming tunnel" was set up and calibrated for measuring oxygen consumption rates of fish swimming at maximum sustained, and intermediate, swimming levels.

The locally constructed Blazka chamber provided an ideal technique. The chamber, considerably modified from the original

designs (Blazka, Volf, and Cepela, 1960; Smith and Newcomb, 1970), is relatively easy to use for measuring oxygen consumption rates and swimming rates up to at least 6 body lengths  $\text{sec}^{-1}$  for a fish as large as 40 cm long. Essentially the clear acrylic plastic chamber is a 19 cm ID tube for the fish and an outside 29 cm OD tube. Water is drawn through the inside tube by means of a pump impeller powered by a 10 hp constant torque variable speed motor. The flow is redirected via a fiberglass (glass reinforced plastic) cone within a dome back through the outside tube, through a cone and dome redirection, and back through the inside tube containing the fish. The chamber flow is preceded by a set of "egg-crate" baffles and two 4 mm screens to "linearize" the flow as described by Mar (1959) for water tunnels of the type used by J. R. Brett in his extensive studies. A screen in the cone in front of the impeller and behind the fish effectively excludes a fish from the impeller. The 63 cm respiration chamber is detachable from the cone-and-dome arrangements at each end; when in use it is gasketed and "quick-lock" clamped at each end to the cone-and-dome arrangements. The entire 207-liter rig is suspended from an overhead trolley so that when it is opened by unclamping and unsealing the aft portion of the respiration chamber, the entire fore part of the rig can be moved away from the cone-and-dome arrangement containing the impeller. The entire rig is suspended in a temperature controlled aquarium making the addition or removal of fish and the cleaning of the chamber an easy task. The motor shaft goes through a stuffing box in the aquarium wall against, which is bolted the cone-and-dome arrangement containing the impeller.

In the fore and aft top part of the respiration chambers are two 30 mm access tubes cemented between the outer and inner tubes. A paddle wheel electronic transducer type of yacht speedometer mounted on the end of a tube slightly smaller than 30 mm fitted with two O-rings can be inserted into either access tube and at any vertical level to measure flow rates, which are read directly from the speedometer mounted outside and attached via the coaxial wire inside the tube on which the transducer unit was mounted.

Impeller shaft speeds are measured by means of a stroboscopic revolution counter system. The shaft RPM was then calibrated and collated with the speedometer readings at vertical flow-rate profiles across the diameter of the inner respiration chamber tube to create flow profiles across the tube. It is then possible to measure the flow rate and swimming speed by direct reading of the shaft RPM so that the access hole can be plugged when metabolic runs are made. With few exceptions fish tend to swim in the maximum velocity portion of the flow-rate profile near the center of the tube. To prevent some fish from nosing up to the anterior screen (and thus altering or "blocking" the flow-rate profile), the addition of small 5-10 cm long x 2-4 mm wide plastic streamers on the screen served well. Details of the hydrodynamics of fish swimming that are pertinent to flows in such a chamber are given by Webb (1975).

When the chamber was immersed and filled, oxygen bubbles were bled from outlet-inlet-tubes with stopcocks at the uppermost water level in the cone-dome junctures. For oxygen analyses,

water samples were withdrawn by syringe through a capillary tubing through a stopper in one of the 30 mm access tubes to the respiration chamber.

As may be noted in Table 14, the protocol for use of fish sometimes resulted in successive measurements on one fish. The total times of the runs varied from 1-3 hours depending on the size of the fish and swimming speeds. All fish were run at 28°C and at salinity levels of 10, 15, 20, 25, 30, 35, 40 and 45 ppt. At zero velocity several fish were in the chamber 8-12 hours overnight, after which the impeller was run briefly before oxygen samples were drawn.

The results were first treated by both averages for each salinity and maximum sustained swimming velocities. The next procedure was to work out the multiple regressions for adjacent salinity levels as for the above data. Finally linear equations of the third and fourth orders that related the average oxygen consumption rates per kilogram at maximum swimming rates to the salinity were calculated by the methods outlined in Snedecor and Cochran (1967).

#### Source of Waters for Experiments

Sea water from the Port Aransas Marine Laboratory was used throughout for the sea water experiments. No pollution or contamination was ever noted for these waters during the year. Waters from Nueces, San Antonio and Lavaca Bays were obtained by pumping into four 500-gal. tanks on a barge towed to the sampling sites and back for use in the laboratory. These sites are:



Nueces Bay USGS Line 53, Site 3

San Antonio Bay USGS Line 264, Site 2

Lavaca Bay USGS Line 90, Site 3.

The series of 1975-76 experiments and pertinent Tables for data were based on waters as follows:

Nueces Bay	October-November 1975	(Table 1)
Sea Water	November-December 1975	(Table 5)
Sea Water	January-February 1976	(Table 6)
San Antonio Bay	February-March 1976	(Table 8)
Lavaca Bay	April 1976	(Table 10)
Nueces Bay	May-July 1976	(Table 12)
Sea Water (Blazka)	July-October 1976	(Table 14)

In addition, work on San Antonio and Lavaca waters is continuing, but will not be included in this report. Blazka sea water experiments at 10, 40, and 45 ppt are appended in Table 14.



## RESULTS

Autumn Nueces Bay Waters

At the termination of the pilot project in August 1975 the only salinity effects in Nueces Bay waters investigated were at 15 and 25 ppt. By October-November these studies began at 35 and 45 ppt to provide metabolic comparisons with fish in sea waters at the same salinities.

The results of these determinations are in Table 1. When the standard and active metabolic levels appeared to have the opposite relationship of Nueces Bay water experiments from the 1975 July-August data in comparison to seawater data, it was noted that the spotted seatrout by late summer and autumn were notably thinner than summer fish, and in some cases actually appeared to be emaciated. (Mr. Ernest Simmons of the Texas Parks and Wildlife Department, Rockport in personal communications noted that spotted seatrout from Laguna Madre were often too emaciated to be sold commercially at that time.)

Accordingly, the 1975 summer and the 1976 autumn fish were compared by means of log weight-log length regressions given in Table 2 with analysis of covariance statistics in Table 3. The slopes differ considerably; the  $b_s = 2.71$  is much greater than the abnormally low  $b_a = 1.80$ . From Guest and Gunter (1958) a value of 2.91 was calculated for comparison of the log weight-log length regression slope pertinent to much more normal, well-nourished conditions. From the analysis of variance data in Table 3, the log weights for length-adjusted means are also different.

The equations in multiple regression form for the autumn and summer data (from the pilot project, where pertinent) are in

Table 1. Autumn data for multiple regression calculations of spotted seatrout respiratory metabolism rates in relation to selected salinities of Nueces Bay (NB) waters, fish weights and lengths, and swimming velocities. Temperature controlled at 28°C.

Date	Experiment Number	Salinity (ppt)	Length (mm)	Log Weight (g)	Swimming Velocity (Lsec <sup>-1</sup> ) (cm)	Log mg O <sub>2</sub> hr <sup>-1</sup>	Log mg O <sub>2</sub> Kg <sup>-1</sup> hr <sup>-1</sup>
5 X 75	NB3A	35	346	2.5416	0.87	1.9288	2.3872
6 X 75	NB3B	35	315	2.4771	0.45	1.8209	2.3438
	NB3C	35	351	2.6107	1.03	2.0747	2.4640
	NB3D	35	360	2.6415	0.89	2.0700	2.4285
	NB3E	35	360	2.5933	0.46	1.9957	2.4024
	NB3F	35	395	2.7126	0.76	2.0510	2.3384
	NB3G	35	431	2.8363	0.36	2.0721	2.2358
	NB3H	35	396	2.7709	0.62	2.0997	2.3288
7 X 75	NB3I	35	444	2.8585	0.28	2.1672	2.3086
	NB3J	35	359	2.6191	0.85	1.8471	2.2280
	NB3K	35	305	2.3222	0.75	1.8267	2.5045
	NB3L	35	298	2.3345	0.33	1.5809	2.2465
	NB3M	35	307	2.3692	0.65	1.9826	2.6134
	NB3N	35	294	2.3304	0.81	1.7683	2.4379
	NB3O	35	285	2.2718	0.62	1.8631	2.5913

(Table 1 cont.)

	Means	35.0	349.7	2.55264	0.649	1.94325	2.39061
20 X 75	NB4A	45	304	2.3345	0.53	1.8341	2.4996
	NB4B	45	290	2.2788	0.71	1.7625	2.4837
	NB4C	45	270	2.1790	0.83	1.8153	2.6363
	NB4D	45	295	2.3541	0.61	1.8412	2.4871
	NB4E	45	332	2.5079	0.00	1.8816	2.3738
23 X 75	NB4F	45	150	2.4771	0.00	0.9912	1.5144
	NB4G	45	341	2.4757	0.27	1.9410	2.4653
	NB4H	45	392	2.6721	0.42	2.0032	2.3309
	NB4I	45	284	2.2718	0.00	1.7077	2.4359
	NB4J	45	199	1.7924	0.78	1.3655	2.5731
5 XI 75	NB4K	45	287	2.2601	0.70	1.7959	2.5359
	NB4L	45	300	2.3404	0.60	1.8006	2.4602
	NB4M	45	320	2.4330	0.56	1.8421	2.4091
	NB4N	45	248	2.1106	0.57	1.6138	2.5033
	Means	45.0	286.6	2.32054	0.470	1.72825	2.40774

Table 2. Analysis of covariance of log weight-log length relationships between summer and autumn groups of Cynoscion nebulosus.

Sums of squares and products, and regression coefficients.  
(Tabulated values rounded to four decimal places.)

Source of Variation	Degrees of Freedom	Sums of Squares and Products			Regressions
		$l^2$	$w^2$	$lw$	
Within Summer	58	0.1607	1.4310	0.4357	$b_s = 2.7102$
Within Autumn	28	0.2529	1.4955	0.4540	$b_A = 1.7954$
Within Seasons	86	0.4137	2.92659	0.8898	$b_a = 2.1509$
Between Seasons	1	0.0671	0.95010	0.2526	$b_m = 3.7613$
Total	87	0.4808	3.8766	1.1424	$b_o = 2.3758$

Regressions of log weight (g) on log total length (mm)

Summer fish:  $\log \text{ weight} = -4.3821 + (2.7102)(\log \text{ length})$

Autumn fish:  $\log \text{ weight} = -2.0382 + (1.7954)(\log \text{ length})$

Table 3. Data for analysis of covariance of log weight-log length relationships for Cynoscion nebulosus in summer and autumn samples. (Tabulated values rounded to four decimal places.)

Source of Variation	Errors of Estimates		
	DF	Sums of Squares	Mean Squares
Deviations from linear regressions within seasons	84	$S_1 =$ 0.9302	0.0110
Differences between season regressions	1	$S_2 =$ 0.0822	0.0822
Deviations within seasons from average regression $b_a$	85	$S_1+S_2 =$ 1.0125	0.0119
Deviations between seasons from mean regression $b_m$	0	$S_3 =$ 0.0	0.0
Differences between $b_a$ and $b_m$	1	$S_4 =$ 0.1498	0.1498
Deviations between seasons for testing significance of "adjusted" means	1	$S_3+S_4 =$ 0.1498	0.1498
Total deviation from regression $b_o$	86	$S_1+S_2+S_3+S_4$ = 1.1622	--

Tests of significance:

$$\text{Slopes: } F = \frac{MS_2}{MS_1} = \frac{0.082...}{0.011...} = 7.43(1, 84DF)**; 0.05 > P > 0.01$$

$$\text{Adjusted means: } F = \frac{MS_4}{MS_1+MS_2} = \frac{0.149...}{0.011...} = 12.58(1, 85DF)**$$

$$0.05 > P > 0.01$$



Table 4. These data are unusually variable but the  $b_w$  and  $b_v$  coefficients are statistically significant at less than the  $P < 0.01$  level. The small salinity coefficients,  $b_s$ , are not statistically significant.

The autumn Nueces Bay standard and routine metabolic levels at 35 and 45 ppt can be compared with the summer data at 15 and 25 ppt, in relation to the entire salinity range for the summer standard and routine levels as in Fig. 1. Quite clearly the autumn Nueces Bay levels are depressed to correspond with the weight-losses and with incipient or actual morbidity.

#### Autumn and Winter Sea Water Series

These data are for the purpose of comparing salinity effects on standard and routine metabolic levels and routine scope to determine whether optimum scope values shift from the summer optimum of about 20 ppt.

The November-December data in Table 5 are all collected at 25°C, a moderately high late autumn temperature. The winter data at 15°C for January-February in Table 6 represent a fairly realistic low temperature representative of most winters in south Texas coastal waters. The salinity differences in both series are small (14-25 ppt) and would be generally representative of coastal primary and secondary bays north of the Laguna Madre.

Table 7 contains the multiple regression equations for adjacent, and various combinations of, salinity levels for the separate autumn and winter series. All the weight,  $b_w$ , coefficients are highly significantly different from zero. Salinity coefficients  $b_s$ , are significant at least below  $P < 0.05$  for equations 12, 14, 15, and 17. Swimming coefficients,  $b_v$ , are significant at or below

Table 4. Multiple regression equations for oxygen consumption rates of Cynoscion nebulosus in Nueces Bay waters at salinities of 35 and 45 ppt and at 28°C. Autumn 1975; also Summer 1975\* plus Autumn 1975 to include lower salinities.

Experiment Numbers	Salinities (ppt)	N	Expected Log mg O <sub>2</sub> hr <sup>-1</sup>	Constant	Log Wt., X <sub>w</sub> (g)	Salinity, X <sub>s</sub> (ppt)	Velocity, X <sub>v</sub> , Lengths (cm) (L sec <sup>-1</sup> )	Multiple Correlation R
NB24A-J <sup>a</sup> (7)	24-35	24	$\hat{Y}$	= -0.3024	+0.8629X <sub>w</sub>	-0.0034X <sub>s</sub>	+ 0.2333X <sub>v</sub>	0.89
NB35A-N + NB45A-N (8)	35-45	28	$\hat{Y}$	= -0.3204	+0.7506X <sub>w</sub>	+0.0032X <sub>s</sub>	+ 0.3493X <sub>v</sub>	0.74
NB24A-J <sup>a</sup> , +NB35A-N, +NB45A-N (9)	24-45	38	$\hat{Y}$	= -0.3542	+0.7911X <sub>w</sub>	+0.0023X <sub>s</sub>	+ 0.2964X <sub>v</sub>	0.79
NB15A-J <sup>a</sup> +NB24A-J <sup>a</sup> +NB35A-N +NB35A-N (10)	15-45	48	$\hat{Y}$	= -0.1453	+0.7899X <sub>w</sub>	-0.0019X <sub>s</sub>	+ 0.2268X <sub>s</sub>	0.77

<sup>a</sup> Data used from Summer experiments. See Pilot Project Report.

Figure 1. Comparison of standard and routine metabolic levels of Cynoscion nebulosus in Nueces Bay and sea waters of various salinities and in summer and autumn. Upper dotted line is for routine summer metabolic levels in sea waters; lower dotted line for summer standard metabolic levels in sea water. Encircled points are for Nueces Bay waters: at 15-25 ppt for summer routine (upper) and standard (lower) metabolic levels and for corresponding autumn data at 34-35 and 45 ppt. Autumn fish in relatively poor condition with appreciable natural weight loss. All data at 28°C.

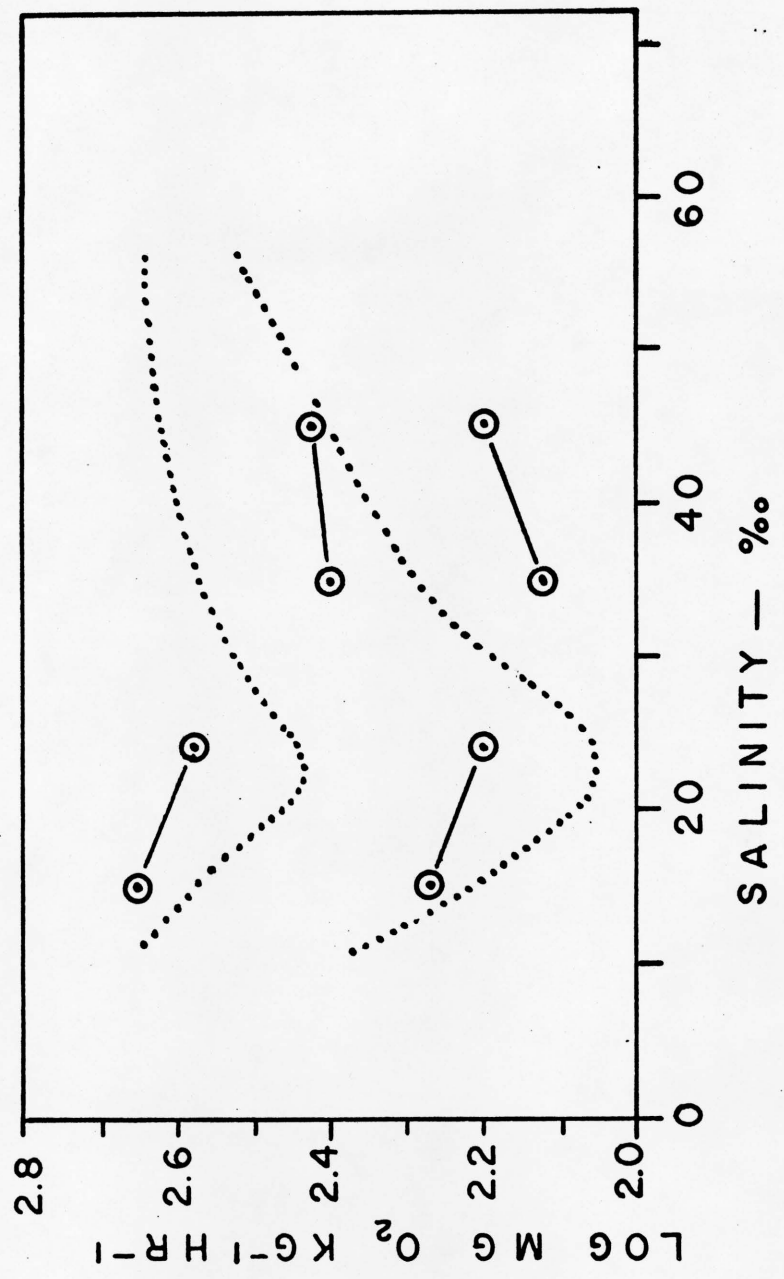


Table 5. November-December, 1975 data for multiple regression calculations of spotted seatrout respiratory metabolism rates in relation to selected seawater salinities, fish weights and lengths, and swimming velocities. Temperature controlled at 25°.

Date	Experiment Number	Salinity (ppt)	Length (mm)	Log Weight (g)	Swimming Velocity (L sec <sup>-1</sup> ) (cm)	Log mg O <sub>2</sub> hr <sup>-1</sup>	Log mg O <sub>2</sub> Kg <sup>-1</sup> hr <sup>-1</sup>
22 XII 75	SW14A	14.0	212	1.8388	1.07	1.2180	2.3792
	SW14B	14.0	263	2.1173	0.65	1.4470	2.3297
24 XII 75	SW14C	14.0	392	2.5803	0.50	1.9704	2.2901
	SW14D	14.0	364	2.6284	0.59	1.9784	2.3500
	SW14E	14.0	388	2.6794	0.54	2.0090	2.3296
26 XII 75	SW14F	14.0	435	2.8751	0.29	2.0586	2.1835
	SW14G	14.0	410	2.7419	0.32	1.9187	2.1767
29 XII 75	SW14H	14.0	372	2.6866	0.57	1.8814	2.1947
	SW14I	14.0	408	2.7380	0.57	1.9616	2.2236
	SW14J	14.0	422	2.7810	0.35	1.8847	2.1048
Means	N=10	14.0	366.6	2.56668	0.545	1.83279	2.25619
<hr/>							
16 XII 75	SW18.4A	18.4	271	2.2041	0.74	1.5390	2.3348
	SW18.4B	18.4	198	1.7482	1.05	1.3284	2.5802



(Table 5 cont.)

17 XII 75	SW18.4C	18.4	248	2.1106	0.59	1.3876	2.2770
	SW18.4D	18.4	185	1.6435	1.23	1.2079	2.5644
	SW18.4E	18.4	238	1.9823	0.89	1.2180	2.2357
18 XII 75	SW18.4F	18.4	236	2.0000	0.60	1.4176	2.4176
	SW18.4G	18.4	252	2.0864	0.74	1.4263	2.3400
	SW18.4H	18.4	254	2.0719	1.04	1.4496	2.3777
	SW18.4I	18.4	207	1.8451	0.66	1.2370	2.3919
	SW18.4J	18.4	219	1.8808	0.76	1.4346	2.5538
Means	N=10	18.4	230.8	1.95729	0.830	1.36460	2.40731
-----							
25 XII 75	SW22.7A	22.7	305	2.4609	0.79	1.9076	2.4467
	SW22.7B	22.7	236	2.0682	0.48	1.5085	2.4403
	SW22.7C	22.7	306	2.4216	0.53	1.8719	2.4503
	SW22.7D	22.7	373	2.7076	0.74	2.0590	2.3514
11 XII 75	SW23A	23	237	2.0334	0.89	1.4302	2.3968
	SW23B	23	226	2.0000	0.98	1.5398	2.5398
	SW23C	23	236	2.0000	1.24	1.5156	2.5156
	SW23D	23	288	2.2788	1.06	1.7644	2.4856
	SW23E	23	241	2.0755	1.24	1.5623	2.4867

(Table 5 cont.)

12 XII 75	SW23F	23	211	1.8195	0.55	1.2923	2.4727
	SW23G	23	203	1.7853	1.06	1.2774	2.4921
	SW23H	23	194	1.7324	0.78	1.2033	2.4709
	SW23I	23	418	2.8215	0.48	2.0472	2.2256
	SW23J	23	218	1.9031	0.98	1.3701	2.4671
Means	N=14	22.9	263.7	2.15056	0.843	1.59640	2.44583
<hr/>							
20 XI 75	SW25A	25	145	1.3979	0.94	1.0803	2.6823
	SW25B	25	277	2.3909	0.00	1.6792	2.2882
	SW25C	25	353	2.6721	0.47	2.0148	2.3427
	SW25D	25	370	2.7202	0.22	2.0321	2.3120
	SW25E	25	330	2.5705	0.43	1.9892	2.4187
	SW25F	25	304	2.4409	0.43	1.8396	2.3987
23 XI 75	SW25G	25	310	2.4969	0.90	1.9064	2.4095
	SW25H	25	312	2.4594	0.60	1.8824	2.4230
	SW25I	25	372	2.6866	0.65	2.0269	2.3402
24 XI 75	SW25J	25	318	2.5119	0.91	1.9202	2.4083

(Table 5 cont.)

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	SW25K	25	325	2.5647	1.02	1.9948	2.4301
	SW25L	25	315	2.4942	1.05	1.8434	2.3493
Means	N=12	25	310.9	2.45052	0.635	1.85078	2.40025

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Table 6. January-February, 1976 data for multiple regression calculations of spotted seatrout respiratory metabolism rates in relation to selected salinities of sea water (SW), fish weights and lengths, and swimming velocities. Temperature controlled at 15°C.

Date	Experiment Number	Salinity (ppt)	Length (mm)	Log Weight (g)	Swimming Velocity (L sec <sup>-1</sup> ) (cm)	Log mg O <sub>2</sub> hr <sup>-1</sup>	Log mg O <sub>2</sub> Kg <sup>-1</sup> hr <sup>-1</sup>
9 I 76	SWA14.2A	14.2	401	2.7419	0.66	1.8671	2.1252
	SWA14.2B	14.2	403	2.7427	0.76	1.9894	2.2467
	SWA14.2C	14.2	382	2.6830	0.63	1.8556	2.1726
	SWA14.2D	14.2	406	2.7574	0.59	1.9922	2.2348
	SWA14.2E	14.2	403	2.7664	0.21	1.8399	2.0735
	SWA14.2F	14.2	370	2.6243	0.60	1.8513	2.2270
	SWA14.2G	14.2	397	2.7243	0.45	1.9401	2.2158
	SWA14.2H	14.2	405	2.7767	0.00	1.8456	2.0689
	SWA14.2I	14.2	400	2.7924	0.28	2.0237	2.2313
	Means	14.20	396.3	2.73434	0.464	1.91166	2.17731
21 I 76	SWA17.2A	17.2	248	2.1335	0.94	1.2455	2.1120
	SWA17.2B	17.2	332	2.5315	0.00	1.5935	2.0620
	SWA17.2C	17.2	259	2.1703	0.78	1.4691	2.2988
	SWA17.2D	17.2	284	2.2455	1.40	1.6497	2.4042

(Table 6 cont.)

23 I 76	SWA17.2E	17.2	390	2.7016	0.31	1.5435	1.8419
	SWA17.2F	17.2	255	2.1461	0.53	1.4029	2.2568
	SWA17.2G	17.2	349	2.5809	0.63	1.6253	2.0444
	SWA17.2H	17.2	371	2.6222	0.39	1.6283	2.0061
	SWA17.2I	17.2	254	2.0934	1.15	1.0881	1.9947
	SWA17.2J	17.2	226	1.9191	1.24	1.2982	2.3791
	Means	17.20	296.8	2.31441	0.737	1.45441	2.14000
27 I 76	SWA22.7A	22.7	268	2.1931	1.26	1.6063	2.4132
	SWA22.7B	22.7	273	2.2330	1.29	1.4595	2.2265
	SWA22.7C	22.7	335	2.4728	1.09	1.5637	2.0909
	SWA22.7D	22.7	304	2.3626	1.27	1.6146	2.2510
	SWA22.7E	22.7	246	2.0755	1.52	1.4794	2.4039
29 I 76	SWA22.7F	22.7	393	2.7039	0.52	1.9721	2.2682
	SWA22.7G	22.7	218	1.9345	1.15	1.1915	2.2570
	SWA22.7H	22.7	210	1.8692	1.07	1.1326	2.2634
30 I 76	SWA22.7I	22.7	236	2.0374	0.93	1.2728	2.2354
	SWA22.7J	22.7	269	2.1931	0.82	1.4019	2.2088
	Means	22.70	275.2	2.20761	1.092	1.46944	2.26183



(Table 6 cont.)

2 II 76	SWA23.9A	23.9	122	1.0792	1.86	0.4249	2.3457
	SWA23.9B	23.9	127	1.1761	1.07	0.4270	2.2509
3 II 76	SWA23.9C	23.9	117	1.0170	0.66	0.3619	2.3449
	SWA23.9D	23.9	139	1.2967	1.04	0.6730	2.6763
	Means	23.90	126.3	1.14225	1.158	0.47170	2.32945
23 II 76	SWA24.7A	24.7	297	2.3284	0.84	1.4519	2.1235
	SWA24.7B	24.7	302	2.3424	0.89	1.6742	2.3318
	SWA24.7C	24.7	360	2.5866	0.46	1.8032	2.2166
	SWA24.7D	24.7	269	2.2148	0.82	1.4793	2.2645
	SWA24.7E	24.7	257	2.1335	1.00	1.0821	1.9486
24 II 76	SWA24.7F	24.7	285	2.2480	0.56	1.4325	2.1845
	SWA24.7G	24.7	279	2.2253	0.73	1.2858	2.0605
	Means	24.70	292.7	2.29700	0.757	1.45843	2.16657

Table 7. Multiple regression equations for oxygen consumption rates of Cynoscion nebulosus in sea waters at selected salinities and at 25°C and 15°C. Winter data.

Experiment Numbers	Salinities (ppt)	N	Expected Log mg. O <sub>2</sub> hr <sup>-1</sup>	Constant	Log Wt., $X_w$ (g)	Salinity, $X_s$ (ppt)	Velocity, $X_v$ Lengths (cm) (L sec <sup>-1</sup> )	Multiple Correlation R
At 25°C (November-December):								
SW14A-J +SW18.4A-J	(11) 14-18.4	20	$\hat{Y} =$	-0.2238	+0.7957 $X_w$	-0.0031 $X_s$	+0.1070 $X_v$	0.97
SW18.4A-J +SW23A-J	(12) 18.4-23	24	$\hat{Y} =$	-0.6150	+0.8179 $X_w$	+0.0155 $X_s$	+0.1147 $X_v$	0.96
SW23A-J +SW25A-L	(13) 22.7-25	26	$\hat{Y} =$	-0.4974	+0.8198 $X_w$	+0.0112 $X_s$	+0.0907 $X_v$	0.99
All salinities(14)	14-25	46	$\hat{Y} =$	-0.5196	+0.8356 $X_w$	+0.0102 $X_s$	+0.0974 $X_v$	0.98
At 15°C (January-February):								
SWA14.2A-I +SWA17.2A-J	(15) 14.2-17.2	19	$\hat{Y} =$	1.0854	+0.6516 $X_w$	-0.0707 $X_s$	+0.1058 $X_v$	0.93
SWA17.2A-J +SWA22.7A-J	(16) 17.2-22.7	20	$\hat{Y} =$	-0.6825	+0.8024 $X_w$	+0.0108 $X_s$	+0.1282 $X_v$	0.84
SWA22.7A-J +SWA24.7A-J	(17) 22.7-24.7	20*	$\hat{Y} =$	-0.1734	+0.9148 $X_w$	-0.0189 $X_s$	+0.0466 $X_v$	0.98
All salinities(18)	14.2-24.7	40	$\hat{Y} =$	-0.6118	+0.9037 $X_w$	-0.0036 $X_s$	+0.1332 $X_v$	0.96

\*One aberrant value deleted.

$P < 0.05$  for all but equations 16 and 17; the negative  $b_v$  in 17 is possibly caused by pectoral rowing and non-locomotory (spontaneous) activity of slower swimming fish at high energy cost, while the faster swimmers utilize less energy costly caudal propulsion.

Table 7a is a collection of multiple regressions across the autumn  $25^{\circ}\text{C}$  and the winter  $15^{\circ}\text{C}$  temperature levels to allow for the calculation of the temperature coefficient  $b_t$  over the entire, but small, salinity ranges in equations 19 and 20. The salinity coefficient (e.g. 21) in the combined data is not significantly different from zero ( $P \approx 0.1$ ); all other  $b_w$ ,  $b_t$  and  $b_v$  are significantly different from zero at least at  $P < 0.05$ , and mostly at considerably lower probabilities.

The standard levels of  $\log \text{O}_2 \text{ kg}^{-1} \text{ hr}^{-1}$  for each salinity group of both  $15^{\circ}\text{C}$  and  $25^{\circ}\text{C}$  data (as extrapolated back to  $b_v = 0$  from the lowest point in each group) and the corresponding average routine levels are plotted in the top panel of Fig. 2. The bottom panel contains the plots of routine scope at  $15^{\circ}$  and  $25^{\circ}\text{C}$ .

#### San Antonio Bay Late Winter Data

The San Antonio Bay (SAB) waters at an ambient salinity of about 10.9 ppt and a temperature of about  $15^{\circ}\text{C}$  were initially utilized for the respiratory metabolic determinations. To account for any very low temperatures during occasional years when coastal water temperatures can drop to  $10^{\circ}\text{C}$  or less,  $10^{\circ}\text{C}$  series were run at 10.9 ppt and at 20.0 ppt. A series at  $15^{\circ}$  and 20.0 ppt was run to evaluate salinities higher than those usually found in San Antonio Bay. Results of these four series are in Table 8.

Table 7a. Same as Table 7, but including partial regression coefficients,  $b_t$ , for temperature,  $X_t$ , over low, high and total salinity ranges.

Experiment Numbers	Temps. (°C)	Salinities (ppt)	N	Expected Log mg O <sub>2</sub> hr <sup>-1</sup>	Constant	Log Wt. $X_w$ (g)	Temp., $X_t$ (°C)	Salinity, $X_s$ (ppt)	Velocity $X_v$ (L sec <sup>-1</sup> )	Multiple Correlation R
SW14A-J +SW18.4A-J +SWA14.2A-I +SWA17.2A-J (19)	15-25	14.0-18.4	39	$\hat{Y}$	= -0.8154	+0.8736 $X_w$	+0.0136 $X_t$	+.....	+0.1435 $X_v$	0.93
SW22.7A-D +SW23A-J +SW25A-L +SWA22.7A-J +SWA23.9A-D +SWA24.7A-G (20)	15-25	22.7-25.0	47	$\hat{Y}$	= -0.9457	+0.8797 $X_w$	+0.0231 $X_t$	+.....	+0.0926 $X_v$	0.98
All of above (21)	15-25	14.0-25.0	86	$\hat{Y}$	= -1.0141	+0.8937 $X_w$	+0.0190 $X_t$	+0.0041 $X_s$	+0.1164 $X_v$	0.97

Figure 2. Late autumn ( $25^{\circ}\text{C}$ ) and winter ( $15^{\circ}\text{C}$ ) metabolic data for Cynoscion nebulosus over restricted salinity range in sea waters. Encircled points and solid lines for November-December data at  $25^{\circ}\text{C}$ ; points in triangles and dashed lines for January-February data at  $15^{\circ}\text{C}$ . In top panel the upper line of each of the paired visually drawn solid or dashed lines represents the routine metabolic levels; the lower of the visually drawn paired lines represents standard metabolism. In lower panel the scope is plotted for  $25^{\circ}$  and  $15^{\circ}$  data to show optimal salinity response at about 20 ppt.



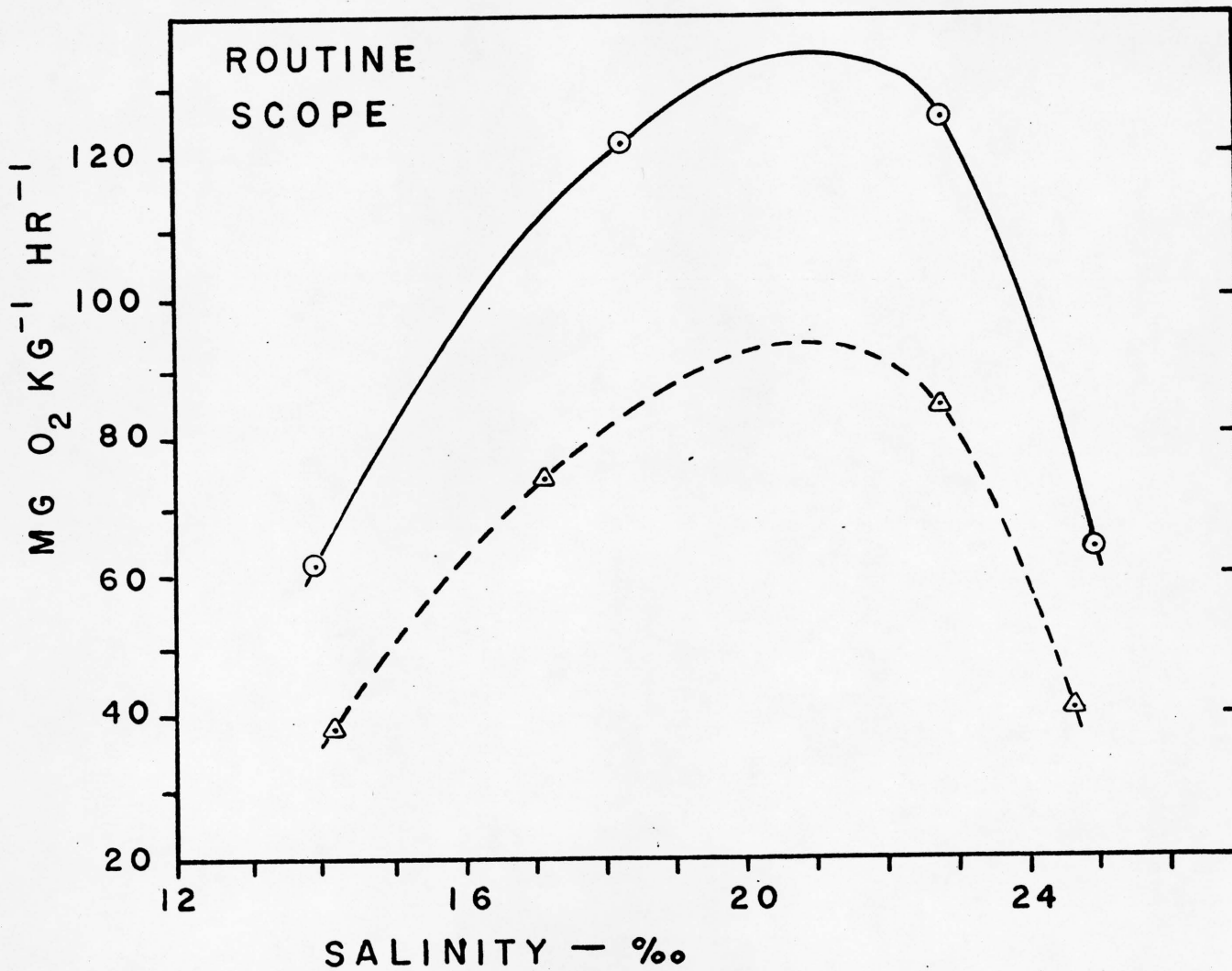
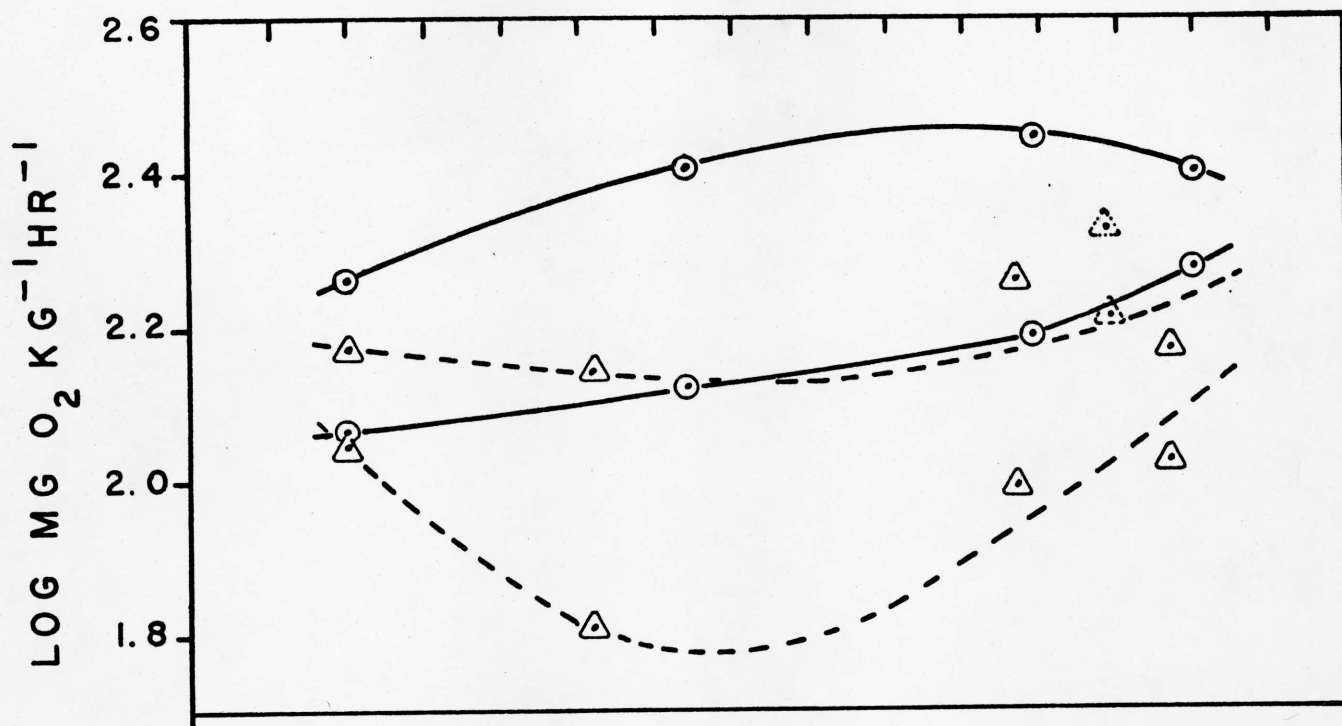


Table 8. San Antonio Bay (SAB) data for multiple regression calculations of Cynoscion nebulosus respiratory metabolism rates in relation to selected salinities, temperatures, fish weights and lengths, and swimming velocities. February-March, 1976.

Date	Experiment Number	Temp. (°C)	Salinity (ppt)	Length (mm)	Log Weight (g)	Swimming Velocity (L sec <sup>-1</sup> ) (cm)	Log mg O <sub>2</sub> hr <sup>-1</sup>	Log mg O <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>
27 II 76	SAB1A	15.0	10.9	251	2.1492	0.47	1.3649	2.2157
	SAB1B	15.0	10.9	288	2.3222	0.63	1.4370	2.1148
	SAB1C	15.0	10.9	260	2.2041	1.14	1.5163	2.3122
1 III 76	SAB1D	15.0	10.9	368	2.6395	0.51	1.8329	2.1934
	SAB1E	15.0	10.9	245	2.0969	1.44	1.4181	2.3212
	SAB1F	15.0	10.9	387	2.6693	0.92	2.0055	2.3362
	SAB1G	15.0	10.9	265	2.2227	1.31	1.5570	2.3343
2 III 76	SAB1H	15.0	10.9	245	2.0934	0.34	1.2842	2.1908
	SAB1I	15.0	10.9	243	2.1038	0.67	1.1284	2.0246
	SAB1J	15.0	10.9	280	2.2504	0.72	1.2041	1.9534
	Means	15.0	10.90	283.2	2.27515	0.815	1.47484	2.19966
9 III 76	SAB2A	10.0	10.9	224	1.9138	0.51	0.6096	1.6958
	SAB2B	10.0	10.9	292	2.3010	0.49	1.0722	1.7712
	SAB2C	10.0	10.9	278	2.2833	0.75	1.3672	2.0839

(Table 8 cont.)

	SAB2D	10.0	10.9	317	2.4362	0.64	1.3655	1.9293
	SAB2E	10.0	10.9	360	2.5843	0.70	1.5880	2.0037
10 III 76	SAB2F	10.0	10.9	262	2.1523	0.68	1.1149	1.9626
	SAB2G	10.0	10.9	376	2.6435	0.51	1.6848	2.0413
	SAB2H	10.0	10.9	245	2.1038	0.58	1.1186	2.0148
	Means	10.0	10.90	294.3	2.30228	0.615	1.24010	1.93783
11 III 76	SAB3A	10.0	20.0	343	2.5635	0.32	1.5339	1.9704
	SAB3B	10.0	20.0	375	2.6884	0.00	1.5301	1.8417
	SAB3C	10.0	20.0	408	2.8116	0.22	1.6245	1.8129
	SAB3D	10.0	20.0	399	2.7482	0.27	1.7260	1.9778
	SAB3E	10.0	20.0	363	2.6571	0.47	1.5971	1.9400
12 III 76	SAB3F	10.0	20.0	413	2.7987	0.00	1.6461	1.8474
	SAB3G	10.0	20.0	400	2.8055	0.24	1.6637	1.8582
13 III 76	SAB3H	10.0	20.0	424	2.8209	0.52	1.8476	2.0267
	SAB3I	10.0	20.0	249	2.1492	1.35	1.3359	2.1867
	SAB3J	10.0	20.0	340	2.5453	0.39	1.5423	1.9970
	Means	10.0	20.00	371.4	2.65884	0.378	1.60472	1.94588
29 III 76	SAB4A	15.0	20.0	378	2.7126	0.76	1.7892	2.0766
	SAB4B	15.0	20.0	360	2.6232	0.75	1.5724	1.9492

(Table 8 cont.)

30	III	76	SAB4C	15.0	20.0	298	2.4150	0.21	1.5967	2.1817
			SAB4E	15.0	20.0	430	2.9365	0.21	1.9810	2.0445
31	III	76	SAB4F	15.0	20.0	354	2.5185	0.23	1.6004	2.0819
			SAB4G	15.0	20.0	354	2.5944	0.45	1.7922	2.1978
			SAB4H	15.0	20.0	415	2.8426	0.45	2.0055	2.1629
			SAB4I	15.0	20.0	276	2.3010	0.63	1.6369	2.3359
			SAB4J	15.0	20.0	245	2.0792	0.58	1.3485	2.2693
			Means	15.0	20.0	345.6	2.55811	0.419	1.70253	2.14442

Multiple regression equations for various salinity combinations are in Table 9. In an attempt to evaluate effects of deleting some of the more disparate measurements, the calculated  $\hat{Y}$  values were compared to the observed  $Y$ . When the differences between  $\hat{Y}$  and  $Y$  were beyond 2 standard deviations, the regressions were recalculated after deletion of these values, as indicated for the alternative equations in Table 9. While these deletions only slightly "improved" an overall regression and the individual partial coefficient, there usually was little biological reason for the deletions. In any case, all the multiple regressions were highly significant at  $P < 0.001$ ; all the  $b_w$  at  $P < 0.001$ ;  $b_s$  all non-significant; all  $b_t$  at  $P < 0.001$ , except (24) with  $P < 0.005$ ; and the  $b_v$  at  $P < 0.05$  to  $P < 0.001$ .

#### Lavaca Bay Spring Data

The April waters from Lavaca Bay had an ambient salinity of about 19.0 ppt and a temperature of about  $15^{\circ}\text{C}$ , which were the initial conditions for experimentation. Other experimental sets included temperature-salinity regimes of  $25^{\circ}\text{C}$  and 20 ppt,  $24^{\circ}\text{C}$  and 30 ppt, and  $15^{\circ}\text{C}$  and 30 ppt. The results are in Table 10.

Regression statistics for various combinations of temperature and salinity levels are in Table 11 along with alternative equations with successive deletions when the observed  $Y$  exceeded the  $\hat{Y}$  by 2 or more standard deviations. Here the purpose of the deletions was to determine empirically whether the several statistically non-significant and negative  $b_v$  could be altered to positive values, since the  $X_v$  were highly variable in relation to the small range of swimming activity, much of which evidently was non-locomotory. Since none of the  $b_v$  were significant and since the



Table 9. Multiple regression equations for oxygen consumption rates of Cynoscion nebulosus in San Antonio Bay (SAB) water at 10°-15°C and at 10.9 (ambient) and 15.0 ppt. salinity. Equations "modified" by deletions of aberrant data denoted as 22a, etc.

Experiment Numbers and Deletions	Temps. (°C)	Salinities (ppt)	N	Expected Log mg O <sub>2</sub> hr <sup>-1</sup>	Constant	Log Wt. X <sub>w</sub> (g)	Temp. X <sub>t</sub> (°C)	Salinity X <sub>s</sub> (ppt)	Velocity X <sub>v</sub> (L sec <sup>-1</sup> )	Multiple Correlation R	(Eq.)
SAB1A-J +SAB4A-J	15.0	10.9-15.0	19	$\hat{Y} =$	-0.8595	+0.9226X <sub>w</sub> + ...		+0.0056X <sub>s</sub> + 0.2134X <sub>v</sub>		0.92	(22)
-SAB1J			18	$\hat{Y} =$	-0.7632	+0.9128X <sub>w</sub> + ...		+0.0024X <sub>s</sub> + 0.1970X <sub>v</sub>		0.94	(22a)
SAB2A-H +SAB3A-J	10.0	10.9-20.0	18	$\hat{Y} =$	-1.8406	+1.2266X <sub>w</sub> + ...		+0.0020X <sub>s</sub> + 0.3826X <sub>v</sub>		0.97	(23)
-SAB2A			17	$\hat{Y} =$	-1.3819	+1.0551X <sub>w</sub> + ...		+0.0034X <sub>s</sub> + 0.3023X <sub>v</sub>		0.96	(23a)
SAB1A-J +SAB2A-H	10.0-15.0	10.9	18	$\hat{Y} =$	-2.1764	+1.2283X <sub>w</sub> + 0.0438X <sub>t</sub> + ...			+ 0.2444X <sub>v</sub>	0.95	(24)
-SAB1J -SAB2A			16	$\hat{Y} =$	-1.8820	+1.1191X <sub>w</sub> + 0.0441X <sub>t</sub> + ...			+ 0.2128X <sub>v</sub>	0.95	(24a)
SAB3A-J +SAB4A-J	10.0-15.0	20.0	19	$\hat{Y} =$	-0.8906	+0.7855X <sub>w</sub> + 0.0339X <sub>t</sub> + ...			+0.1786X <sub>v</sub>	0.93	(25)
-SAB4B			18	$\hat{Y} =$	-0.9184	+0.7836X <sub>w</sub> + 0.0379X <sub>t</sub> + ...			+0.1601X <sub>v</sub>	0.95	(25a)
All data	10.0-15.0	10.9-20.0	37	$\hat{Y} =$	-1.7437	+1.0284X <sub>w</sub> + 0.0400X <sub>t</sub> + 0.0055X <sub>s</sub> + 0.2626X <sub>v</sub>				0.94	(26)
-SAB1J -SAB2A -SAB4B			34	$\hat{Y} =$	-1.4938	+0.9464X <sub>w</sub> + 0.0410X <sub>t</sub> + 0.0045X <sub>s</sub> + 0.2165X <sub>v</sub>				0.95	(26a)

Table 10. Spring data for multiple regression calculations of Cynoscion nebulosus respiratory metabolism rates in relation to selected salinities of Lavaca Bay (LB) waters, temperatures, fish weights and lengths, and swimming velocities.

Date	Experiment Number	Temp. (°C)	Salinity (ppt)	Length (mm)	Log Weight (g)	Swimming Velocity (L sec <sup>-1</sup> ) (cm)	Log mg O <sub>2</sub> hr <sup>-1</sup>	Log mg O <sub>2</sub> Kg <sup>-1</sup> hr <sup>-1</sup>
6 IV 76	LB1A	15.0	19.0	269	2.1703	0.83	0.9854	1.8151
	LB1B	15.0	19.0	355	2.5563	0.64	1.7820	2.2257
	LB1C	15.0	19.0	323	2.4594	0.43	1.3377	1.8783
	LB1D	15.0	19.0	408	2.7634	0.35	1.9436	2.1802
	LB1E	15.0	19.0	375	2.6435	0.66	1.7029	2.0594
8 IV 76	LB1F	15.0	19.0	396	2.6335	0.37	1.8228	2.1893
	LB1G	15.0	19.0	443	2.9395	0.40	2.0604	2.1209
	LB1H	15.0	19.0	405	2.8102	0.41	1.9644	2.1542
9 IV 76	LB1I	15.0	19.0	375	2.7634	0.50	1.9674	2.2040
	LB1J	15.0	19.0	324	2.5263	0.40	1.6990	2.1360
	Means	15.00	19.00	372.3	2.62658	0.499	1.72656	2.09631
12 IV 76	LB2A	25.0	20.0	378	2.6928	0.36	2.0154	2.3226
	LB2B	25.0	20.0	380	2.7135	0.49	1.9111	2.1976
	LB2C	25.0	20.0	408	2.7973	0.39	2.0469	2.2496

(Table 10 cont.)

	LB2D	25.0	20.0	367	2.6464	0.44	1.9599	2.3135
	LB2E	25.0	20.0	361	2.6031	0.40	1.9392	2.3361
13 IV 76	LB2F	25.0	20.0	296	2.3655	0.54	1.8821	2.5166
	LB2G	25.0	20.0	367	2.6628	0.28	1.9539	2.2911
	LB2H	25.0	20.0	260	2.1461	0.46	1.6486	2.5025
	LB2I	25.0	20.0	262	2.1367	0.58	1.4894	2.3527
	LB2J	25.0	20.0	264	2.1523	0.56	1.6443	2.4920
	Means	25.00	20.00	334.3	2.49165	0.450	1.84908	2.35743
16 IV 76	LB3A	24.0	30.0	396	2.7709	0.57	2.0696	2.2987
	LB3B	24.0	30.0	352	2.6075	0.52	1.8535	2.2460
	LB3C	24.0	30.0	356	2.6212	0.52	1.9235	2.3023
19 IV 76	LB3D	24.0	30.0	343	2.5490	0.52	1.7972	2.2481
	LB3E	24.0	30.0	292	2.2945	0.58	1.6495	2.3550
20 IV 76	LB3F	24.0	30.0	236	2.0334	1.12	1.3334	2.3000
21 IV 76	LB3G	24.0	30.0	384	2.7185	0.00	1.8120	2.0935
	LB3H	24.0	30.0	301	2.3766	0.57	1.8193	2.4427
	LB3I	24.0	30.0	388	2.6998	0.44	2.0932	2.3934
	Means	24.00	30.00	338.7	2.51904	0.538	1.81680	2.29776

(Table 10 cont.)

26 IV 76	LB4A	15.0	30.0	297	2.3909	0.29	1.2826	1.8917
	LB4B	15.0	30.0	372	2.6513	0.55	1.7116	2.0603
27 IV 76	LB4C	15.0	30.0	378	2.6721	0.49	1.6702	1.9981
	LB4D	15.0	30.0	317	2.4533	0.52	1.6406	2.1873
	LB4E	15.0	30.0	416	2.8325	0.37	1.9566	2.1241
	LB4F	15.0	30.0	412	2.7952	0.32	2.0567	2.2615
29 IV 76	LB4G	15.0	30.0	390	2.7024	0.36	1.9526	2.2502
	LB4H	15.0	30.0	423	2.8248	0.14	1.8344	2.0096
	LB4I	15.0	30.0	327	2.5315	0.22	1.6547	2.1232
	LB4J	15.0	30.0	410	2.8169	0.49	1.8294	2.0125
	Means	15.00	30.00	374.2	2.66719	0.375	1.75894	2.09185

Table 11. Multiple regression equations for oxygen consumption rates of *Cynoscion nebulosus* in Lavaca Bay (LB) waters at selected salinities and temperatures. April data. Equations "modified" by deletions of aberrant data denoted as 27a, etc.

Experiment Numbers and Deletions	Temp. (°C)	Salinity (ppt)	Expected Log mg O <sub>2</sub> hr <sup>-1</sup> N	Log Wt. X <sub>w</sub> (g)	Temp. X <sub>t</sub> (°C)	Salinity X <sub>s</sub> (ppt)	Velocity X <sub>v</sub> (L sec <sup>-1</sup> )	Multiple Correlation	(Eq.)
LB1A-J +LB4A-J	15.0	19.0-30.0	20	$\hat{Y} =$	-1.2544	+1.1883X <sub>w</sub> + ...	-0.0032X <sub>s</sub> - 0.1586X <sub>v</sub>	0.85	(27)
-LB1A, C, G -LB4A, F, G			14	$\hat{Y} =$	+0.3949	+0.6827X <sub>w</sub> + ...	-0.0129X <sub>s</sub> - 0.2075X <sub>v</sub>	0.82	(27a)
-LB1A, C, F, G -LB4A, F, G			13	$\hat{Y} =$	+1.9917	+0.7614X <sub>w</sub> + ...	-0.0090X <sub>s</sub> - 0.0876X <sub>v</sub>	0.90	(27b)
-LB1A, C, E, F, G -LB4A, F, G			12	$\hat{Y} =$	-0.0086	+0.7711X <sub>w</sub> + ...	-0.0103X <sub>s</sub> + 0.0124X <sub>v</sub>	0.93	(27c)
LB2A-G +LB3A-I	24.0-25.0	20.0-30.0	19	$\hat{Y} =$	+0.0496	+0.7620X <sub>w</sub> + ...	-0.0055X <sub>s</sub> + 0.0258X <sub>v</sub>	0.91	(28)
-LB2B -LB3G, H			16	$\hat{Y} =$	+0.2367	+0.7075X <sub>w</sub> + ...	-0.0017X <sub>s</sub> - 0.2364X <sub>v</sub>	0.96	(28a)
-LB2B, F -LB3G, H, I			14	$\hat{Y} =$	+0.2197	+0.7076X <sub>w</sub> + ...	-0.0021X <sub>s</sub> - 0.2191X <sub>v</sub>	0.98	(28b)



(Table 11. cont.)

LB1A-J +LB2A-J	15.0-25.0	19.0-20.0	20	$\hat{Y} =$	-0.1856	+0.7216 $X_w$	+0.0193 $X_t$	+...	-0.5468 $X_v$	0.85	(29)
-LB1A,C,G -LB2B			16	$\hat{Y} =$	+0.3005	+0.6069 $X_w$	+0.0081 $X_t$	+...	-0.3544 $X_v$	0.89	(29a)
-LB1A,C,F,G -LB2B			15	$\hat{Y} =$	-0.1596	+0.6927 $X_w$	+0.0139 $X_t$	+...	-0.1212 $X_v$	0.93	(29b)
-LB1A,C,F,G -LB2B,F,I			13	$\hat{Y} =$	+0.0283	+0.6371 $X_w$	+0.0125 $X_t$	+...	-0.1595 $X_v$	0.96	(29c)
LB3A-I +LB4A-J	15.0-24.0	30.0	19	$\hat{Y} =$	-1.5153	+1.0838 $X_w$	+0.0208 $X_t$	+...	+0.1913 $X_v$	0.89	(30)
-LB3G-H -LB4A,F,G			14	$\hat{Y} =$	-0.8537	+0.8466 $X_w$	+0.0257 $X_t$	+...	-0.1156 $X_v$	0.96	(30a)
All data			39	$\hat{Y} =$	-1.0104	+0.9260 $X_w$	+0.0236 $X_t$	-0.0018 $X_s$	-0.0189 $X_v$	0.85	(31)
-LB1A,C,G -LB2B -LB3G,H -LB4A,F,G			30	$\hat{Y} =$	-0.2656	+0.7658 $X_w$	+0.0174 $X_t$	-0.0076 $X_s$	-0.0995 $X_v$	0.91	(31a)
-LB1A,C,F,G -LB2B -LB3G,H,I -LB4A,F,G			28	$\hat{Y} =$	-0.3130	+0.7621 $X_w$	+0.0181 $X_t$	-0.0070 $X_s$	-0.0683 $X_v$	0.95	(31b)

(Table 11. cont.)

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-LB1A, C, F, G  
-LB2B, F  
-LB3G, H, I  
-LB4A, F, G

$$27 \quad \hat{Y} = -0.3517 + 0.7740X_w + 0.0175X_t - 0.0064X_s - 0.0667X_v + 0.96 \quad (31c)$$

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$b_v$  negative tendency could not be removed by manipulation, the value  $b_v = 0.15$  was arbitrarily used to extrapolate from the lowest  $Y \text{ kg}^{-1}$  and  $X_v$  data point to estimate the standard level for each of the data sets. Interestingly, all the  $b_w$  were significant at less than  $P < 0.001$  except for Eq. 29 ( $P < 0.005$ ). For salinity coefficients significance at  $P < 0.05$  was evident for Eqs. 27a, b, c, 28, and 31a, b, c. The  $b_t$  were all significant at  $P < 0.025$  or less, except for Eq. 29a.

#### Nueces Bay Spring and Summer Data

In Table 12 are the results for the data sets:  $15^\circ\text{C}$  and 32 ppt,  $24^\circ\text{C}$  and 32 ppt,  $15^\circ\text{C}$  and 20 ppt,  $25^\circ\text{C}$  and 20 ppt, and  $15^\circ\text{C}$  and 10 ppt. Note that the dates do not necessarily correspond to seasonally changing temperatures and salinities. At the low temperature and salinity levels of July, two comatose fish were apparently ill-adapted to these levels and were omitted from further calculations.

The multiple regressions are in Table 13. After some of the more biologically obvious discrepant values were deleted, alternative regression calculations were made, but the extended elimination of data, as in the previous section, was dispensed with. All the  $b_w$  and  $b_t$  coefficients are statistically significant at  $P < 0.001$ ; none of the  $b_s$  is significant; all the  $b_v$  are significant at  $P < 0.025$  or less, except for  $b_v$  in Eqs. 33, 33a, 35, which are not significant.

Table 12. May-July, 1976 Nueces Bay (NB) data for multiple regression calculations of Cynoscion nebulosus respiratory metabolism rates in relation to selected salinities, temperatures, fish weights and lengths, and swimming velocities.

Date	Experiment Number	Temp. (°C)	Salinity (ppt)	Length (mm)	Log Weight (g)	Swimming Velocity (L sec <sup>-1</sup> ) (cm)	Log mg O <sub>2</sub> hr <sup>-1</sup>	Log mg O <sub>2</sub> Kg <sup>-1</sup> hr <sup>-1</sup>
5 V 76	NB5A	15.0	32.0	291	2.3096	0.28	1.4087	2.0991
	NB5B	15.0	32.0	364	2.6232	0.24	1.7231	2.0999
	NB5C	15.0	32.0	305	2.3655	0.29	1.1798	1.8143
	NB5D	15.0	32.0	420	2.7404	0.42	1.8461	1.7457
	NB5E	15.0	32.0	209	1.8573	0.85	0.8306	1.9733
7 V 76	NB5F	15.0	32.0	407	2.8222	0.27	1.6110	1.7888
	NB5G	15.0	32.0	320	2.5263	0.77	1.6347	2.1084
	NB5H	15.0	32.0	287	2.3385	0.46	1.2133	1.8748
	NB5I	15.0	32.0	343	2.5866	0.63	1.7451	2.1585
	Means	15.00	32.00	327.3	2.46329	0.468	1.46582	1.96253
10 V 76	NB6A	24.0	32.0	344	2.5198	0.53	1.8020	2.2822
	NB6B	24.0	32.0	342	2.5051	0.52	1.8024	2.2973
	NB6C	24.0	32.0	344	2.5658	0.82	1.8681	2.3023
	NB6D	24.0	32.0	280	2.2742	0.64	1.6322	2.3580

(Table 12 cont.)

	NB6E	24.0	32.0	343	2.5623	0.75	1.9563	2.3940
12 V 76	NB6F	24.0	32.0	328	2.4843	0.41	1.7459	2.2616
	NB6G	24.0	32.0	310	2.4249	0.33	1.6496	2.2247
	NB6H	24.0	32.0	434	2.7505	0.22	1.8605	2.1100
	NB6I	24.0	32.0	396	2.7210	0.79	2.0111	2.2901
	NB6J	24.0	32.0	315	2.4409	1.00	1.9282	2.4873
	Means	24.00	32.00	343.6	2.52488	0.601	1.82563	2.30075
25 V 76	NB7A	15.0	20.0	350	2.5625	0.46	1.4393	1.8758
28 V 76	NB7B	15.0	20.0	351	2.5599	0.54	1.6231	2.0632
	NB7C	15.0	20.0	369	2.6149	0.44	1.6386	2.0237
	NB7D	15.0	20.0	359	2.6075	0.59	1.4984	1.8835
	NB7E	15.0	20.0	394	2.7490	0.73	1.8952	2.1462
	NB7F	15.0	20.0	378	2.7160	0.66	1.7575	2.0415
31 V 76	NB7G	15.0	20.0	434	2.8274	0.31	1.9837	2.1563
	NB7H	15.0	20.0	320	2.4594	0.30	1.8395	2.3801
	NB7I	15.0	20.0	400	2.7993	0.23	1.5323	1.7335
	Means	15.00	20.00	372.8	2.65521	0.473	1.68979	2.03376



(Table 12 cont.)

11 VI 76	NB8A	25.0	20.0	345	2.5514	0.33	1.8087	2.2573
	NB8B	25.0	20.0	326	2.4378	0.55	1.5822	2.1444
	NB8C	25.0	20.0	230	2.0086	0.69	1.3664	2.3578
	NB8D	25.0	20.0	412	2.8325	0.38	2.2239	2.3914
	NB8E	25.0	20.0	312	2.3802	0.75	1.7329	2.3527
21 VI 76	NB8F	25.0	20.0	251	2.1335	0.68	1.5135	2.3800
	NB8G	25.0	20.0	269	2.2201	0.71	1.5113	2.2912
	NB8H	25.0	20.0	315	2.4654	0.67	1.8195	2.3541
	NB8I	25.0	20.0	273	2.2148	0.78	1.6332	2.4184
	NB8J	25.0	20.0	308	2.3655	0.71	1.7210	2.3555
	Means	25.00	20.00	304.1	2.36098	0.625	1.69126	2.33028
23 VI 76	NB9A	25.0	10.0	290	2.3181	0.60	1.5022	2.1841
	NB9B	25.0	10.0	312	2.4654	0.53	1.8030	2.3376
	NB9C	25.0	10.0	346	2.5465	0.83	1.9292	2.3827
24 VI 76	NB9D	25.0	10.0	316	2.4281	0.79	1.7088	2.2807
	NB9E	25.0	10.0	270	2.2553	0.76	1.5230	2.2677
	NB9F	25.0	10.0	288	2.2923	0.88	1.7204	2.4281
	NB9G	25.0	10.0	279	2.3054	0.93	1.7151	2.4097

(Table 12 cont.)

	NB9H	25.0	10.0	297	2.3139	1.01	1.8315	2.5176
25 VI 76	NB9I	25.0	10.0	352	2.5611	0.56	1.9535	2.3924
	NB9J	25.0	10.0	274	2.2504	0.93	1.7354	2.4850
	Means	25.00	10.00	302.4	2.37365	0.782	1.74221	2.36856
28 VI 76	NB10A	15.0	10.0	348	2.5752	0.64	1.6299	2.0547
	NB10B	15.0	10.0	279	2.2967	0.81	1.3214	2.0247
	NB10C	15.0	10.0	292	2.3096	0.55	1.4730	2.1634
	NB10D	15.0	10.0	251	2.1335	0.37	0.9112	1.7777
7 VII 76	<del>NB10E</del>	<del>15.0</del>	<del>10.0</del>	<del>291</del>	<del>2.3502</del>	<del>0.00</del>	<del>0.3434</del>	<del>0.9932</del> *
	NB10F	15.0	10.0	270	2.2742	0.27	1.0881	1.8139
8 VII 76	NB10G	15.0	10.0	259	2.1271	0.42	1.0137	1.8866
	NB10H	15.0	10.0	296	2.3096	0.73	1.3813	2.0717
	NB10I	15.0	10.0	304	2.4082	0.32	1.2858	1.8776
9 VII 76	<del>NB10J</del>	<del>15.0</del>	<del>10.0</del>	<del>278</del>	<del>2.2041</del>	<del>0.34</del>	<del>0.7134</del>	<del>1.5093</del> *
	Means	15.00	10.00	287.4	2.30426	0.514	1.26305	1.95879

\*Comatose fish. Data deleted.

Table 13. Multiple regression equations for oxygen consumption rates of Cynoscion nebulosus in Nueces Bay (NB) waters at selected salinities and temperatures. May-July data.

Experiment Numbers	Temp. (°C)	Salinity (ppt)	N	Expected Log mg O <sub>2</sub> hr <sup>-1</sup>	Constant	Log Wt. X <sub>w</sub> (g)	Temp. X <sub>t</sub> (°C)	Salinity X <sub>s</sub> (ppt)	Velocity X <sub>v</sub> (L sec <sup>-1</sup> )	Multiple Correlation	(Eq.)
NB5A-I +NB6A-J	15.0-24.0	32.0	19	$\hat{Y} =$	-1.7426	+1.0734X <sub>w</sub>	+0.0281X <sub>t</sub>	+...	+0.3044X <sub>v</sub>	0.95	(32)
NB7A-I +NB8A-J	15.0-25.0	20.0	19	$\hat{Y} =$	-2.1369	+1.1741X <sub>w</sub>	+0.0337X <sub>t</sub>	+...	+0.3413X <sub>v</sub>	0.88	(33)
-NB7G,I -NB8B	15.0-25.0	20.0	16	$\hat{Y} =$	-2.0356	+1.1461X <sub>w</sub>	+0.0358X <sub>t</sub>	+...	+0.2328X <sub>v</sub>	0.95	(33a)
NB9A-J +NB10A-I	15.0-25.0	10.0	18	$\hat{Y} =$	-2.3031	+1.2697X <sub>w</sub>	+0.0261X <sub>t</sub>	+...	+0.4833X <sub>v</sub>	0.97	(34)
NB5A-I +NB7A-I	15.0	20.0-32.0	18	$\hat{Y} =$	-1.7924	+1.2062X <sub>w</sub>	+...	+0.0004X <sub>s</sub>	+0.3129X <sub>v</sub>	0.90	(35)
NB6A-J +NB8A-J	24.0-25.0	20.0-32.0	20	$\hat{Y} =$	-0.8284	+1.0005X <sub>w</sub>	+...	-0.0018X <sub>s</sub>	+0.3106X <sub>v</sub>	0.95	(36)
-NB8B,D	24.0-25.0	20.0-32.0	18	$\hat{Y} =$	-0.5878	+0.8767X <sub>w</sub>	+...	+0.0003X <sub>s</sub>	+0.3155X <sub>v</sub>	0.97	(36a)
NB8A-J +NB9A-J	25.0	10.0-20.0	20	$\hat{Y} =$	-1.4165	+1.1764X <sub>w</sub>	+...	+0.0031X <sub>s</sub>	+0.4286X <sub>v</sub>	0.93	(37)
-NB8B -NB9D	25.0	10.0-20.0	18	$\hat{Y} =$	-1.4769	+1.2061X <sub>w</sub>	+...	+0.0038X <sub>s</sub>	+0.4215X <sub>v</sub>	0.96	(37a)

(Table 13. cont.)

NB5A-I +NB6A-J +NB7A-I +NB8A-J	15.0-25.0	20.0-32.0	38	$\hat{Y} =$	-1.8288	+1.0854 $X_w$	+0.0299 $X_t$	+0.0007 $X_s$	+0.3006 $X_v$	0.92	(38)
-NB5A, B, F -NB7G, I -NB8B	15.0-25.0	20.0-32.0	32	$\hat{Y} =$	-2.0166	-1.1493 $X_w$	+0.0325 $X_t$	-0.0011 $X_s$	+0.3403 $X_v$	0.97	(38a)
NB7A-I +NB8A-J +NB9A-J +NB10A-I	15.0-25.0	10.0-20.0	37	$\hat{Y} =$	-2.1506	+1.1807 $X_w$	+0.0310 $X_t$	+0.0009 $X_s$	+0.4053 $X_v$	0.95	(39)
-NB7D, G, I -NB8B -NB10C	15.0-25.0	10.0-20.0	32	$\hat{Y} =$	-2.2696	+1.2034 $X_w$	+0.0326 $X_t$	+0.0038 $X_s$	+0.3516 $X_v$	0.98	(39a)
All data	15.0-25.0	10.0-32.0	56	$\hat{Y} =$	-1.9837	+1.1305 $X_w$	+0.0299 $X_t$	+0.0010 $X_s$	+0.3625 $X_v$	0.94	(40)
-NB5A, B, F -NB7G -NB8B -NB10C	15.0-25.0	10.0-32.0	50	$\hat{Y} =$	-2.1510	+1.1612 $X_w$	+0.0328 $X_t$	+0.0010 $X_s$	+0.4047 $X_v$	0.97	(40a)

Maximum Sustained Swimming Velocity  
- Blazka Respiration Experiments

These 28°C experiments included fish from July-August, and from September-October, 1976 as an extension of the pilot project one year earlier. By subsets at 5 ppt intervals and without subset averages, the data for 10 to 45 ppt are assembled in Table 14. (Since many of the fish were intentionally run at minimum and maximum  $X_V$ , averages are not useful.) In addition to  $X_V$ , the  $X_V \times \sqrt{L}$ , where  $L$  is the total fish length in cm, are tabulated.

In Table 15 are the multiple regressions calculated for adjacent 5 ppt salinity intervals. Not only are the overall regressions, 41-44, very highly significant, the  $b_W$  and  $b_V$  are significant at levels far less than  $P < 0.001$ . Only the  $b_S$  in Eq. 44 is significant at  $P < 0.05$ .

To determine any effects that the  $X_V$  might have on the other variables, Eq. 41 was recalculated by replacing the  $X_V$  with  $X_{SS}$  swimming speeds in  $\text{cm sec}^{-1}$  (not tabulated). This equation is:

$$\hat{Y} = -0.5943 + 1.0363 X_W - 0.0057 X_S + 0.0043 X_{SS},$$

with  $R = 0.95$  and with  $b_W$  and  $b_{SS}$  significant at much less than  $P < 0.001$ , but with non-significant  $b_{SS}$ .

For the purpose of identifying individual fish data at maximum sustained swimming levels the superscript "1" is used in Table 14. For identifying the fish at resting ( $X_V = 0$ ) levels, the superscript "2" is used in Table 14. By using only the averages of the maximum log oxygen consumption rate  $\text{kg}^{-1} \text{hr}^{-1}$  ( $\bar{Y} \text{ kg}^{-1} \text{hr}^{-1}$ ) at each salinity a fourth-order relationship between  $\bar{Y} \text{ kg}^{-1} \text{hr}^{-1}$  and salinity  $X_S$  in a quartic linear form (rounded to 4 significant digits) is:



Table 14. Seawater data from Blazka chamber experiments on Cynoscion nebulosus 28°C respiratory metabolism rates in relation to selected salinities, fish weights and lengths, and swimming velocities. July-Aug. 1976.

Date	X <sub>S</sub> Salinity (ppt)	L Length (cm)	X <sub>W</sub> Log Weight (g)	X <sub>V</sub> Swimming Velocity (L sec <sup>-1</sup> )	X <sub>V</sub> L <sup>1/2</sup> (cms <sup>-1</sup> /√L)	Y Log mg O <sub>2</sub> hr <sup>-1</sup>	Ykg <sup>-1</sup> Log mg O <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>
	35.0	29.2	2.290	2.363	12.769	1.769	2.479
<sup>1</sup>	35.0	29.2	2.290	2.740	14.805	1.921	1.631 <sup>1</sup>
	35.0	30.5	2.301	2.262	12.494	1.778	2.477
<sup>1</sup>	35.0	30.5	2.301	2.623	14.486	1.962	2.661 <sup>1</sup>
<sup>1</sup>	35.0	30.5	2.301	2.623	14.486	2.038	2.737 <sup>1</sup>
	35.0	30.5	2.301	2.262	12.494	1.883	2.582
<sup>1</sup>	35.0	30.5	2.301	2.623	14.486	1.921	2.620 <sup>1</sup>
<sup>2</sup>	35.0	24.9	2.146	0.000	0.000	1.377	2.230 <sup>2</sup>
	35.0	24.9	2.146	2.771	13.828	1.766	2.620
<sup>1</sup>	35.0	24.9	2.146	3.213	16.032	1.769	2.623 <sup>1</sup>
<sup>1</sup>	35.0	24.9	2.146	3.213	16.032	1.840	2.694 <sup>1</sup>
<sup>1</sup>	35.0	24.9	2.146	3.213	16.032	1.813	2.667 <sup>1</sup>
<sup>2</sup>	35.0	31.0	2.447	0.000	0.000	1.723	2.276 <sup>2</sup>

(Table 14. cont.)

<sup>1</sup> 35.0	31.0	2.447	2.581	14.368	2.111	2.664 <sup>1</sup>
<sup>1</sup> 35.0	31.0	2.447	2.581	14.368	2.125	2.678 <sup>1</sup>
<sup>2</sup> 35.0	30.8	2.441	0.000	0.000	1.714	2.273 <sup>2</sup>
<hr/>						
30.0	29.3	2.415	1.945	10.530	2.076	2.661
30.0	29.3	2.415	2.355	12.747	2.109	2.694
30.0	29.3	2.415	2.355	12.747	2.137	2.722
<sup>2</sup> 30.0	29.3	2.415	0.000	0.000	1.700	2.285 <sup>2</sup>
<sup>2</sup> 30.0	29.0	2.384	0.000	0.000	1.694	2.310 <sup>2</sup>
30.0	26.0	2.292	2.594	13.379	1.898	2.606
<sup>1</sup> 30.0	26.6	2.292	3.008	15.511	1.994	2.701 <sup>1</sup>
<sup>1</sup> 30.0	26.9	2.307	2.974	15.425	1.954	2.647 <sup>1</sup>
<sup>2</sup> 30.0	32.2	2.465	0.000	0.000	1.779	2.313 <sup>2</sup>
30.0	32.2	2.465	2.484	14.098	2.109	2.644
<sup>1</sup> 30.0	32.2	2.465	2.857	16.213	2.109	2.644 <sup>1</sup>
<sup>1</sup> 30.0	32.2	2.465	2.857	16.213	2.163	2.698 <sup>1</sup>
<sup>1</sup> 30.0	26.8	2.258	3.843	19.896	1.911	2.653 <sup>1</sup>

(Table 14. cont.)

<sup>2</sup> 30.0	26.8	2.258	0.000	0.000	1.606	2.349 <sup>2</sup>
<sup>1</sup> 30.0	26.7	2.243	3.446	17.805	1.882	2.639 <sup>1</sup>
<sup>2</sup> 30.0	26.7	2.243	0.000	0.000	1.602	2.359 <sup>2</sup>
<hr/>						
25.0	28.5	2.255	0.000	0.000	1.526	2.270
<sup>1</sup> 25.0	24.2	2.146	3.802	18.702	1.973	2.827 <sup>1</sup>
<sup>1</sup> 25.0	28.2	2.246	3.759	19.961	2.078	2.832 <sup>1</sup>
25.0	31.1	2.446	3.183	17.752	2.212	2.767
25.0	31.1	2.446	3.183	17.752	2.201	2.755
25.0	24.4	2.107	2.828	13.969	1.862	2.755
<sup>2</sup> 25.0	29.1	2.380	0.000	0.000	1.593	2.213 <sup>2</sup>
<sup>1</sup> 25.0	29.1	2.380	3.471	18.723	2.176	2.796 <sup>1</sup>
<sup>2</sup> 25.0	28.7	2.350	0.000	0.000	1.704	2.354 <sup>2</sup>
25.0	26.5	2.290	3.472	17.872	2.025	2.734
<hr/>						

(Table 14. cont.)

<sup>1</sup>	20.0	37.8	2.708	3.042	18.705	2.484	2.776 <sup>1</sup>
<sup>1</sup>	20.0	37.8	2.708	3.042	18.705	2.481	2.773 <sup>1</sup>
	20.0	37.8	2.708	2.619	16.102	2.456	2.748
	20.0	37.8	2.703	2.434	14.964	2.470	2.766
	20.0	37.8	2.703	2.434	14.964	2.435	2.732
	20.0	43.5	2.886	1.586	10.462	2.330	2.444
	20.0	43.5	2.886	2.115	13.949	2.435	2.548
	20.0	43.5	2.886	2.664	17.436	2.502	2.615
<sup>2</sup>	20.0	37.8	2.699	0.000	0.000	1.886	2.187 <sup>2</sup>
	20.0	27.0	2.267	2.556	13.279	1.882	2.615
	20.0	27.0	2.267	2.963	15.396	2.037	2.770
<sup>1</sup>	20.0	27.0	2.267	3.741	19.437	2.104	2.837 <sup>1</sup>
<sup>2</sup>	20.0	28.7	2.344	0.000	0.000	1.598	2.254 <sup>2</sup>
<sup>1</sup>	20.0	28.7	2.344	3.519	18.853	2.178	2.834 <sup>1</sup>
	20.0	28.7	2.344	2.404	12.880	1.904	2.560
	20.0	28.7	2.344	1.986	10.640	1.758	2.414
	20.0	28.7	2.344	2.787	14.933	2.037	2.692
<sup>2</sup>	20.0	26.0	2.243	0.000	0.000	1.563	2.320 <sup>2</sup>
<sup>1</sup>	20.0	26.0	2.243	3.885	19.808	2.065	2.822 <sup>1</sup>

(Table 14. cont.)

	20.0	37.8	2.673	2.434	14.964	2.285	2.612
<sup>1</sup>	20.0	25.8	2.201	3.992	20.278	2.037	2.835 <sup>1</sup>
<sup>1</sup>	20.0	25.8	2.201	3.992	20.278	2.072	2.870 <sup>1</sup>
	20.0	23.3	2.013	1.974	9.530	1.560	2.547
	20.0	23.3	2.013	2.961	14.295	1.736	2.723
	20.0	23.3	2.013	3.433	16.573	1.806	2.794
<sup>1</sup>	20.0	23.3	2.013	3.984	19.059	1.912	2.899 <sup>1</sup>

	15.0	27.8	2.212	2.482	13.087	1.835	2.623
	15.0	27.8	2.212	2.878	15.173	1.940	2.278
<sup>1</sup>	15.0	27.8	2.212	3.309	17.449	1.987	2.775 <sup>1</sup>
<sup>2</sup>	15.0	27.8	2.212	0.000	0.000	1.514	2.302 <sup>2</sup>
<sup>2</sup>	15.0	26.4	2.201	0.000	0.000	1.646	2.445 <sup>2</sup>
	15.0	26.4	2.201	2.614	13.429	2.011	2.810
	15.0	26.4	2.201	3.674	18.879	2.049	2.848
	15.0	34.8	2.543	2.299	13.561	2.089	2.546
	15.0	34.8	2.543	2.644	15.595	2.225	2.682
<sup>1</sup>	15.0	34.8	2.543	3.046	17.969	2.350	2.807 <sup>1</sup>
	15.0	26.0	2.188	2.654	13.532	1.947	2.759



(Table 14 cont.)

	15.0	26.0	2.188	3.077	15.689	1.977	2.789
<sup>1</sup>	15.0	26.0	2.188	3.538	18.043	2.049	2.862 <sup>1</sup>
<sup>2</sup>	15.0	26.4	2.248	0.000	0.000	1.572	2.324 <sup>2</sup>
	15.0	26.4	2.248	3.030	15.570	1.979	2.732
	15.0	30.6	2.407	1.863	10.304	2.001	2.594
	15.0	30.6	2.407	2.614	14.462	2.073	2.666
<sup>2</sup>	15.0	35.0	2.519	0.000	0.000	1.845	2.327
<sup>1</sup>	15.0	35.0	2.519	3.029	17.917	2.281	2.763 <sup>1</sup>
<sup>1</sup>	15.0	27.4	2.220	3.613	18.913	1.991	2.771 <sup>1</sup>
	15.0	27.4	2.220	1.679	8.788	1.718	2.498
	15.0	41.1	2.866	2.238	14.350	2.516	2.650

## Supplemental data, September-October 1976:

	10.0	28.2	2.310	2.447	12.993	1.870	2.560
<sup>1</sup>	10.0	28.2	2.310	2.943	15.630	1.982	2.673 <sup>2</sup>
	10.0	26.9	2.223	2.119	10.990	1.761	2.538
	10.0	26.9	2.223	2.565	13.304	1.840	2.617
<sup>1</sup>	10.0	26.9	2.223	2.974	15.425	1.893	2.670 <sup>1</sup>
<sup>2</sup>	10.0	26.9	2.223	0.000	0.000	1.517	2.295 <sup>2</sup>

(Table 15 cont.)

<sup>2</sup>	10.0	31.4	2.444	0.000	0.000	1.846	2.402 <sup>2</sup>
	10.0	31.4	2.444	1.815	10.172	1.982	2.538
	10.0	31.4	2.444	1.815	10.172	1.927	2.483
<sup>1</sup>	10.0	27.4	2.265	2.920	15.283	2.024	2.759 <sup>1</sup>
	10.0	27.4	2.265	1.350	7.068	1.709	2.445
<sup>2</sup>	10.0	27.4	2.265	0.000	0.000	1.584	2.320 <sup>2</sup>
<sup>1</sup>	10.0	31.5	2.447	2.921	16.392	2.186	2.739 <sup>1</sup>
<sup>2</sup>	10.0	31.5	2.447	0.000	0.000	1.730	2.283 <sup>2</sup>
<sup>1</sup>	10.0	26.0	2.167	3.346	17.062	1.907	2.739 <sup>1</sup>
	10.0	28.7	2.326	1.968	10.640	1.885	2.559
<sup>1</sup>	10.0	28.7	2.326	2.892	15.493	2.043	2.717 <sup>1</sup>
<sup>2</sup>	10.0	28.7	2.326	0.000	0.000	1.622	2.296 <sup>2</sup>
<sup>2</sup>	10.0	23.1	2.053	0.000	0.000	1.417	2.364 <sup>2</sup>
	10.0	23.1	2.053	1.991	9.571	1.584	2.531
	10.0	23.1	2.053	2.987	14.356	1.618	2.565
<sup>1</sup>	10.0	23.1	2.053	3.290	15.813	1.789	2.735 <sup>1</sup>
<sup>2</sup>	10.0	23.1	2.053	0.000	0.000	1.401	2.348 <sup>2</sup>

(Table 14 cont.)

<sup>1</sup>	40.0	27.0	2.230	2.889	15.011	1.878	2.648 <sup>1</sup>
	40.0	27.0	2.230	2.556	13.279	1.811	2.581
	40.0	27.0	2.230	2.111	10.970	1.800	2.570
<sup>2</sup>	40.0	27.0	2.230	0.000	0.000	1.590	2.239 <sup>2</sup>
	40.0	29.4	2.290	2.347	12.726	1.936	2.646
<sup>1</sup>	40.0	29.4	2.290	2.517	13.648	1.950	2.660 <sup>1</sup>
	40.0	25.0	2.152	1.840	9.200	1.714	2.562
	40.0	25.0	2.152	2.280	11.400	1.753	2.601
	40.0	25.0	2.152	2.560	12.800	1.811	2.659
<sup>1</sup>	40.0	25.0	2.152	2.760	13.800	1.863	2.710 <sup>1</sup>
<sup>2</sup>	40.0	29.1	2.270	0.000	0.000	1.620	2.350 <sup>2</sup>
	40.0	29.1	2.270	1.959	10.566	1.846	2.577
	40.0	29.1	2.270	2.371	12.791	1.925	2.656
<sup>1</sup>	40.0	29.1	2.270	2.543	13.718	1.936	2.667 <sup>1</sup>
<sup>2</sup>	40.0	29.1	2.270	0.000	0.000	1.645	2.375 <sup>2</sup>
	40.0	25.0	2.107	1.840	9.200	1.635	2.528
	40.0	25.0	2.107	2.280	11.400	1.753	2.646
<sup>1</sup>	40.0	25.0	2.107	2.760	13.800	1.786	2.679 <sup>1</sup>

(Table 14 cont.)

2	40.0	26.4	2.207	0.000	0.000	1.571	2.364 <sup>2</sup>
1	40.0	26.4	2.207	2.803	14.402	1.871	2.664 <sup>1</sup>
	40.0	26.4	2.207	1.288	6.616	1.642	2.435
<hr/>							
	45.0	40.4	2.757	1.139	7.237	2.204	2.447
	45.0	40.4	2.757	1.708	10.856	2.256	2.499
1	45.0	40.4	2.757	1.931	12.272	2.336	2.579 <sup>1</sup>
	45.0	26.3	2.193	1.749	8.970	1.706	2.513
1	45.0	26.3	2.193	2.167	11.115	1.753	2.560 <sup>1</sup>
2	45.0	26.3	2.193	0.000	0.000	1.563	2.370 <sup>2</sup>
	45.0	29.0	2.272	1.586	8.542	1.799	2.527
1	45.0	29.0	2.272	2.069	11.142	1.834	2.562 <sup>1</sup>
2	45.0	25.4	2.155	0.000	0.000	1.548	2.393 <sup>2</sup>
	45.0	25.4	2.155	1.811	9.127	1.644	2.489
	45.0	25.4	2.155	2.008	10.119	1.644	2.489
	45.0	25.4	2.155	2.165	10.913	1.702	2.547
1	45.0	25.4	2.155	2.244	11.310	1.741	2.586 <sup>1</sup>
	45.0	29.3	2.290	1.570	8.498	1.745	2.455

(Table 14 cont.)

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	45.0	29.3	2.290	1.877	10,161	1.799	2.509
<sup>1</sup>	45.0	29.3	2.290	2.048	11.085	1.896	2.606 <sup>1</sup>

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<sup>1</sup> Data at maximum sustained swimming rates.

<sup>2</sup> Data at resting conditions.



Table 15. Multiple regression equations for oxygen consumption rates at 5ppt salinity ranges. Cynoscion nebulosus data from Blazka chamber 28°C experiments including maximum sustained swimming velocities. July-August 1976.

Salinity Range (ppt)	N	Expected Log mg O <sub>2</sub> hr <sup>-1</sup>	Constant	Log Wt. X <sub>W</sub> (g)	Salinity X <sub>S</sub> (ppt)	Velocity X <sub>V</sub> (L sec <sup>-1</sup> )	Multiple Correlation	Equation
30-35	32	$\hat{Y} =$	-1.1379	+1.2364X <sub>W</sub>	-0.0033X <sub>S</sub>	+0.1236X <sub>V</sub>	0.95	41
25-30	26	$\hat{Y} =$	-0.8196	+1.1123X <sub>W</sub>	-0.0044X <sub>S</sub>	+0.1269X <sub>V</sub>	0.96	42
20-25	36	$\hat{Y} =$	-0.8035	+1.0122X <sub>W</sub>	+0.0015X <sub>S</sub>	+0.1555X <sub>V</sub>	0.98	43
15-20	48	$\hat{Y} =$	0.5705	+0.9952X <sub>W</sub>	-0.0073X <sub>S</sub>	+0.1491X <sub>V</sub>	0.98	44
Supplemental data, September-October 1976:								
10-15	45	$\hat{Y} =$	-0.7810	+0.9910X <sub>W</sub>	+0.0108X <sub>S</sub>	+0.1271X <sub>V</sub>	0.98	45
35-40	37	$\hat{Y} =$	-1.559	+1.1699X <sub>W</sub>	+0.0126X <sub>S</sub>	+0.1285X <sub>V</sub>	0.96	46
40-45	37	$\hat{Y} =$	-0.3898	+1.0111X <sub>W</sub>	-0.0067X <sub>S</sub>	+0.1067X <sub>V</sub>	0.98	47
25&35	26	$\hat{Y} =$	- .9233	+1.1407X <sub>W</sub>	-0.0045X <sub>S</sub>	+0.1445X <sub>V</sub>	0.97	48

$$\begin{aligned} \hat{Y} \text{ kg}^{-1} \text{ hr}^{-1} = & 1.9943 + 0.1216X_s - 0.6096 \times 10^{-2} X_s^2 + 0.1230 \times 10^{-3} X_s^3 \\ & - 0.9123 \times 10^{-6} X_s^4 . \end{aligned}$$

The use of sufficient significant digits is mandatory for the higher order coefficients which adequately cover the sinuous metabolism-salinity curve between 10 to 45 ppt but not beyond. The technique of making these calculations is in Snedecor and Cochran (1967) and other statistical books; it is simply an adaptation of the multiple regression technique by using  $X$ ,  $X^2$ ,  $X^3$ , and  $X^4$  as the multiple, independent variables with  $Y/\text{kg}^{-1} \text{ hr}^{-1}$  as the dependent variable.

Since the metabolism and swimming velocity was apparently depressed at 30 ppt because those fish were in poor physical condition, the 30 ppt data were omitted altogether for the above fourth-order equation.

## DISCUSSION

Nueces Bay Autumn Data

From the data and calculations in Table 1 and 4, the log weight-log length analysis of covariance computations in Tables 2 and 3, and the metabolism comparisons in Fig. 1, it is apparent that carnivorous Cynoscion nebulosus undergo a late summer and autumn period of metabolism and growth depression with general debilitation. Since the same situation prevails for the Mugil cephalus, the striped mullet, in later summer months, the need to assemble data to establish whether the growth-metabolism depression is a generality becomes essential (Cech and Wohlschlag, 1975). Quite clearly fish morbidity is inevitable when standard metabolic levels are depressed. From the 35 and 45 ppt metabolic levels and the trend between these levels in Fig. 1, it is easy to see that metabolic scope above the normal standard line of summer fish is much reduced. From data reviewed in Fry (1971), it would appear that routine scope would have to be about twice the standard level to allow for minimum foraging energy and/or the energy required for digestion and assimilation (specific dynamic action). Thus, if the "normal" standard level at 35 ppt for the summer fish is reasonable at about 2.28 log units ( $191 \text{ mg O}_2 \text{ kg}^{-1} \text{ hr}^{-1}$ ), then the comparable autumn routine value of 2.39 log units ( $245 \text{ mg O}_2 \text{ kg}^{-1} \text{ hr}^{-1}$ ) is far short of double the standard rate. In terms of salinity and the position of the standard and routine lines in Fig. 1, it would seem that the "least unfavorable" salinity at this season would certainly be less than 35 ppt.

Since published data on possible food deficiencies and data on the possible cumulative, physiologically adverse effects of sustained high summer temperatures are also unavailable for this area and elsewhere, it seems reasonable to propose that there be conducted much more research on these two possibilities if other environmental stresses are to be evaluated.

These deficiencies could be evaluated either by (1) physiologically oriented studies of freshwater inflows on coastal areas with the use of "standardized" fishes kept on rigid laboratory temperature and feeding regimes or (2) more extensive ecological studies for the evaluation of energetics of fish feeding and food requirement levels especially in late summer. While laboratory studies could efficiently be used for assessing the effects of salinity and temperature stresses, ecological studies would still be required for assessing the availability of food organisms and for determining the efficiency of food utilization, especially under naturally stressed conditions.

In the natural environment there also is the likelihood that larger members of fish populations react more adversely to stress than smaller members. Along the south Texas coast this appears to be true for the pinfish, Lagodon rhomboides as indicated by Wohlschlag and Cameron (1967), Wohlschlag et al. (1968) and Kloth and Wohlschlag (1972). In the case of the autumn data on spotted seatrout (Table 2) the log weight-log length coefficient of 1.8 is so low that the larger fish must certainly have experienced relatively much greater weight losses than the smaller fish.

### Autumn - Winter Seawater Series

This series, designed to yield performance baseline data at colder temperatures, indicates quite clearly that there is little shift in optimal salinities for winter fish (Fig. 2). There is no ready explanation for the differences in Fig. 2 for the 15°C and 25°C standard-routine metabolism data pairs in terms of the shape of the curves. If either the 15°C standard or routine levels are extrapolated upward at 20 ppt to 25°C with a  $b_t \approx 0.02$  (Eq. 21, Table 7a), both levels are somewhat lower than the observed 25°C standard and routine levels. Thus the extrapolation of winter 15°C to autumn 25°C metabolic levels indicates the reverse of cold adaptation in the sense observed for polar fish (Wohlschlag 1964). Holton's (1974) question on the validity of the cold adaptation concept would be affirmed if the 15°C levels extrapolated to 25°C were about equal. Because the upwardly extrapolated levels are lower than expected at approximately corresponding levels of activity, either the  $b_t \approx 0.02$  is much too low or there is a possibility of cold depensation. Either possibility is realistic on the basis of the available data.

By contrast the summer (Fig. 1) routine levels at 28°C are based on much higher swimming rates ( $\chi_v$ ) than the rates observed for the autumn and winter experiments. Allowing for the temperature and activity differences, the 28°C and 25°C data for summer and autumn are reasonably similar.

However, the comparative levels of the routine scope are much higher in the summer at 28°C (see Fig. 3) and near the optimum salinity



level of about 20 ppt than the routine scope levels at autumn and winter (Fig. 2) because of the much higher routine swimming rates in summer.

In Table 16 are the results of an attempt to utilize the various pertinent equations of Table 7 to "adjust" all of the routine rates at the various salinity and two temperature levels to a uniform  $b_v = 1.0$ . As can be observed the newly calculated routine scope values at  $b_v = 1.0$  are rather erratic compared to the values calculated from the observed data. The erratic values are clearly in large part the result of erratic  $b_v$  computations from very low swimming rates by sluggish fish. Because the fish were ordinarily allowed to swim in the chamber at whatever speeds they would swim consistently, the results in the fall and winter are for very slowly swimming fish with a spread of  $X_v$  so small that  $b_v$  values from the multiple regression calculation have very poor precision. Whatever the advantages may be for using routine swimming rates from "naturally" swimming fish, a range of observed  $X_v$  swimming rates from zero to at least  $1.5 \text{ L sec}^{-1}$  would seem desirable for regression calculations of  $b_v$ .

#### San Antonio Bay February-March Data

Because the San Antonio Bay experiments emphasized both low temperature and low salinity aspects of routine and standard metabolism, these data are best compared with the winter seawater series at  $15^\circ\text{C}$  and the lower salinity levels. Calculations for the evaluation of scope for routine activity are in Table 17. At 10.9 and 20.0 ppt and at  $15^\circ\text{C}$  the SAB scope values are both 0.329, which indicates no diminution in scope with declining salinity as

Table 16. Scope for routine metabolism at observed average swimming activity and at calculated values of  $1 \text{ Lsec}^{-1}$  over selected salinity and temperature ranges. Seawater (SW), winter. Cynoscion nebulosus data.

Salinity ppt	Average Activity Lsec <sup>-1</sup>	Routine Activity <sup>1</sup>		Standard Metabolism Log mgO <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>	Scope		Equations for X <sub>y</sub> = 1.0 Calculations
		Observed Log mgO <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>	X <sub>y</sub> = 1.0 Log mgO <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>		Observed mgO <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>	X <sub>y</sub> = 1.0 mgO <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>	
At 25°C, November - December:							
14.0	0.545	2.256	2.315	2.070	62.1	89.0	(11)
18.4	0.830	2.407	2.430	2.125	121.9	135.8	(11), (12)
22.9	0.843	2.446	2.238	2.187	125.5	19.2	(12), (13)
25.0	0.635	2.400	2.432	2.272	64.1	83.3	(13)
At 15°C, January - February:							
14.2	0.464	2.177	2.235	2.049	38.4	59.9	(15)
17.2	0.737	2.140	2.172	1.804	74.3	84.9	(15), (16)
22.7	1.092	2.262	2.255	1.995	83.9	81.0	(16), (17)
23.9 <sup>2</sup>	1.158 <sup>2</sup>	2.329 <sup>2</sup>	2.757	2.202 <sup>2</sup>	54.1 <sup>2</sup>	412.3 <sup>2</sup>	(17)
24.7	0.757	2.167	2.211	2.025	41.0	56.7	(17)

<sup>1</sup> When 2 equations are used, average  $X_v = 1$  responses are calculated.

<sup>2</sup> Based on only 4 observations on small fish.

Table 17: Scope for routine metabolism at observed average routine swimming activity and at selected salinities and temperatures. Cynoscion nebulosus in San Antonio Bay waters. February-March, 1976.

Salinity ppt	Temp. °C	Average Activity Lsec <sup>-1</sup>	Observed Routine Metabolism Log mgO <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>	Standard Metabolism Log mgO <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>	Scope mgO <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>	Equations
10.9	15.0	0.815	2.200	1.871	84.2	22, 24
10.9	10.0	0.615	1.938	1.630	44.0	23, 24
20.0	10.0	0.378	1.946	1.751	31.9	23, 25
20.0	15.0	0.419	2.144	1.815	74.0	25

in case of the seawater plots of Fig. 2, but the scope values at 15°C are about the same at 20 ppt for both winter SW and SAB experiments, but SAB scope is much higher at 10.9°C when compared to an extrapolated value in Fig. 2 SW series. However, in both winter SW and SAB data sets, the standard and routine activity levels tend to be of the same general magnitude if allowance is made for the lower temperature level in the SAB data and slight differences between the SAB and SW swimming velocities.

The similarity of standard and routine metabolic levels of SAB and comparable SW data implies that there are no unusual stress factors in the SAB waters that would elevate or depress metabolism. The lack of SAB stress effects also implies that the 10.9 ppt data at both 10°C and 15°C would be especially useful when combined with multidimensional analyses of scope and other measures of swimming propensities in terms of both salinity and temperature variables.

#### Lavaca Bay Waters - April

The standard and routine metabolic levels for salinities of 19-20 up to 30 ppt and from 15°C to 24-25°C are of the same general levels as those for the seawater and San Antonio Bay waters, if comparable temperatures and salinities are considered.

At the very low swimming speeds the calculation of meaningful oxygen consumption rate-swimming rate coefficients  $b_v$  is difficult as indicated by the data in Table 10 and by the derived regressions in Table 11 in which most of the  $b_v$  are negative. (See Results section above.)

As explained earlier, the energy expended at very low, less efficient swimming rates is quite possibly greater than at higher

swimming rates when well coordinated, highly efficient caudal propulsion is the principal mode of swimming. Webb (1975) summarizes much of the existing information on the relations between swimming speeds and kinematics; he notes that many of the relationships apply to swimming speeds that are higher than  $1-2 \text{ L sec}^{-1}$ . In the Lavaca Bay water experiments, for example, the spotted seatrout swimming speeds averaged less than  $0.5 \text{ L sec}^{-1}$  and it was obvious that the swimming mode(s) at these low speeds appeared to result in "labored" or "clumsy" swimming movements compared to the more effective, typical subcarangiform movements at higher speeds. The transition in swimming modes would be at about  $0.3 - 0.4 \text{ L sec}^{-1}$  for the spotted seatrout and may be associated with the solitary swimming vs. natural schooling energy requirements for propulsion as was observed for an antarctic fish (Wohlschlag, 1965) and for the bluegill (Wohlschlag and Juliano, 1959). Otherwise, the presence of increased "spontaneous activity" (Fry 1957) at the very low  $X_v$  could also be an acceptable explanation for the negative  $b_v$  values. In spite of these small, negative and statistically uninteresting  $b_v$ , the overall equations yield reasonable estimates of  $\hat{Y}$  or  $\hat{Y} \text{ kg}^{-1}$  which agree not only with the average  $\hat{Y} \text{ kg}^{-1} \text{ hr}^{-1}$  from Table 10, but with the averages at comparable temperatures and salinities in the seawater and San Antonio Bay series, as well as with the Nueces Bay series in the following section. The Lavaca Bay scope data are in Table 18, where the values indicate reasonable correspondence with scope values for the San Antonio Bay and winter sea water series.



Table 18. Scope for routine metabolism at observed average routine swimming activity and at selected salinities and temperatures. Cynoscion nebulosus in Lavaca Bay waters. April, 1976

Salinity ppt	Temp. °C	Average Activity Lsec <sup>-1</sup>	Observed Routine Metabolism Log mgO <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>	Standard Metabolism Log mgO <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>	Scope mgO <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>	Equations
19.0	15.0	0.499	2.065 <sup>1</sup>	1.840	46.9	Extrapolated <sup>1</sup>
19.0	15.0	0.462	2.154 <sup>2</sup>	1.840	73.4	Extrapolated <sup>2</sup>
20.0	25.0	0.450	2.357 <sup>3</sup>	2.123	94.8	Extrapolated <sup>3</sup>
30.0	24.0	0.358	2.298	2.094	74.4	30
30.0	15.0	0.375	2.092	1.856	51.8	30 <sup>4</sup>

<sup>1</sup> From regression based on original LB1A-J data and assuming  $b_v = 0.15$ .

<sup>2</sup> From regression based on LB1B-J data and assuming  $b_v = 0.15$ . LB1A deleted.

<sup>3</sup> From regression based on LB2A-J data and assuming  $b_v = 0.15$ .

<sup>4</sup> From average based on regression from LB4A-J data and from Eq. (30).

Nueces Bay Waters - May-July

The original aim of obtaining the Table 12 data and Table 13 equations was for a low temperature comparison of the 1975 summer pilot project and early autumn 1976 series at 28°C. Although this portion of the project was too late in the season for natural "cold water" experiments, the cooling of the waters and the sufficiently long acclimation times at the lower temperatures produced reasonable metabolic rate results, with possibly the exception of the July data at 15° (Table 12). At these low temperatures the July fish may not have been too well acclimated, inasmuch as they appeared "sluggish", while two fish in this series were obviously comatose with insignificant metabolism. Even so the summary of the average routine and standard metabolic rates and the scope in Table 19 indicate no unusual levels considering the low temperatures and the salinity extremes of 10 and 32 ppt. At 24-25°C the standard levels were lower than for the August 1975 pilot project data, whose elevated standard and routine metabolic rates apparently indicated a sublethal level of stress in the Nueces Bay waters at that time.

The 1976 Nueces Bay waters apparently did not influence the standard and routine metabolic levels over and above (or below) those of the seawater experiments at comparable salinities and temperatures. However, the  $\bar{X}_v$  for these data are lower than those at 15 and 25 ppt in the original pilot project data for Nueces Bay, but are about equivalent to those of the depressed autumn 1975 35 and 45 ppt data.

Without major "adjustments" of these Nueces Bay data for swimming velocity differences, the scope values are of the same

Table 19. Scope for routine metabolism at observed average routine swimming activity and at selected salinities and temperatures. Cynoscion nebulosus in Nueces Bay waters. May-July 1976.

Salinity ppt	Temp. °C	Average Activity Lsec <sup>-1</sup>	Observed Routine Metabolism Log mgO <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>	Standard Metabolism Log mgO <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>	Scope mgO <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>	Equations
32.0	15.0	0.468	1.963	1.618	50.3	32, 35
32.0	24.0	0.601	2.301	2.045	89.1	32, 36, 38
20.0	15.0	0.472	2.034	1.696	58.4	33a,38a,39a
20.0	25.0	0.625	2.330	1.974	119.6	33a,36a,38a,39a
10.0	25.0	0.782	2.369	1.952	144.4	37a,39a
10.0	15.0	0.514	1.959	1.623	49.0	34, 39a

order as the autumn seawater series and the series for San Antonio and Lavaca Bays. By contrast: (1) the pilot project NB series had higher standard and routine rates presumably due to sublethal water quality stresses, and (2) the autumn NB series had depressed standard and routine rates presumably due directly to the poor conditions of the "starved" fish.

#### Maximum Scope for Activity

The series of metabolic data at maximum sustained swimming rates, determined with the Blazka apparatus, can give a much more sensitive scope calculation than the routine scope calculations. The rationale for scope as a sensitivity measure of the response by an organism to environmental regimes--or variations among a given set of environmental conditions--has been well documented (Fry 1947, 1957, 1971, and others) with reference to maximum optimal metabolic output at optimal temperatures.

Although there has been limited research on metabolism as related to salinity, the studies of metabolic scope over salinity regimes have been even more limited. In the pilot project for routine scope calculations, the results indicated clearly that a salinity of about 20 ppt provided maximum scope. Whether there would be the same relationship to salinity at a scope value from metabolic data at maximum sustained rates was a primary objective for this portion of the study. Secondary objectives included a comparative assessment of the nature of (a) maximum sustained swimming rates themselves at different salinities, (b) the characteristics of the curves relating maximum, routine and standard metabolism to salinity, and (c) the characteristics of the scope curve.

The data from Table 14 and the calculated regressions from Table 15 provide the summarized information on swimming speeds and metabolism for estimates of scope at 10-45 ppt. (Note that the term  $L \text{ sec}^{-1} / \sqrt{L}$  is the same as velocity in  $\text{cm sec}^{-1} \sqrt{L}$  when  $L$  is fish lengths in cm.). The summary is in Table 20,

The relationships of the metabolism-salinity plots for standard, routine, and maximum sustained metabolism and scope are, for the most part, self explanatory in Figure 3. One obvious fact persists: the optimum salinity at the scope for maximum sustained swimming speed is at about 20 ppt, the same as the salinity level for the scope for routine swimming activity in the preceding sections covering both summer and winter temperature ranges.

It is interesting, and quite useful, to observe that the metabolic rate of the single most active fish at any given salinity as indicated by squares in Fig. 3 suggests a curve that parallels the average maximum metabolic rate vs. salinity points (encircled points).

Another important feature of Figure 3 is that the scope for routine activity at about 10 and 45 ppt implies about twice the standard oxygen consumption rate at routine activity rates. This salinity range in the south Texas coastal region is just about that over which the spotted seatrout regularly occur at least in fair availability to the sport and commercial fisheries.

Fry's (1957) suggestion (from Job's data on small brook trout) that at least twice the standard oxygen consumption rate was required for assimilation would certainly seem rational for



Table 20. Observed and average maximum values for swimming velocities (lengths per second) and velocities per square root of length, log O<sub>2</sub> consumption per kg per hr, and standard metabolism and scope for maximum sustained swimming activity.

Salinity (ppt)	Observed Max. X <sub>V</sub> (L sec <sup>-1</sup> )	Avg. Max. X <sub>V</sub> (L sec <sup>-1</sup> )	Observed Max. X <sub>V</sub> √L	Avg. Max. X <sub>V</sub> √L	Max. Log mg O <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>	Avg. Max. Log mg O <sub>2</sub>	Standard <sup>1</sup> Log mg O <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>	Scope <sup>1</sup> for Max. Activity mgO <sub>2</sub> kg <sup>-1</sup> hr <sup>-1</sup>
35	3.213	2.823	16.032	15.011	2.694	2.664	2.273 <sup>1</sup>	306.8
30	3.843 <sup>2</sup>		19.896 <sup>2</sup>					
		3.164		16.844	2.701	2.664 <sup>3</sup>	2.169 <sup>1</sup>	313.7
30	3.446		17.805					
25	3.802	3.677	18.702	19.129	2.827	2.818	2.072 <sup>1</sup>	539.7
20	3.992	3.646	20.278	19.390	2.870	2.831	2.077 <sup>1</sup>	558.2
15	3.674	3.307	18.913	18.058	2.862	2.796	2.195 <sup>1</sup>	468.5
Supplemental data, September-October, 1976:								
10	3.346	3.041	17.062	15.871	2.759	2.719	2.330 <sup>4</sup>	311.3
40	2.889	2.712	15.011	14.063	2.710	2.671	2.362 <sup>4</sup>	238.7
45	2.244	2.092	12.272	11.385	2.606	2.579	2.382 <sup>4</sup>	138.3

<sup>1</sup> Based on 1975 "Pilot Project" standard metabolism determinations at 15,25,34,35,45 ppt or extrapolated between.

<sup>2</sup> Small fish "sheltered" in chamber; values possibly erroneously high.

<sup>3</sup> Fish in poor condition.

<sup>4</sup> Lowest in Blazka Avg.  $\bar{Y}$  kg<sup>-1</sup> at X<sub>V</sub> = 0.

Figure 3. Upper panel - Metabolism of Cynoscion nebulosus at standard (lower line, diamonds), routine (middle line, triangles) and at maximum sustained activity (upper lines, circles) over a range of salinities. Calculated rates indicated by squares for the various numbered equations from Table 15. Lower panel -- Scope for maximum sustained activity over salinity range 10 - 45 ppt. Arrows indicate "depressed" values.

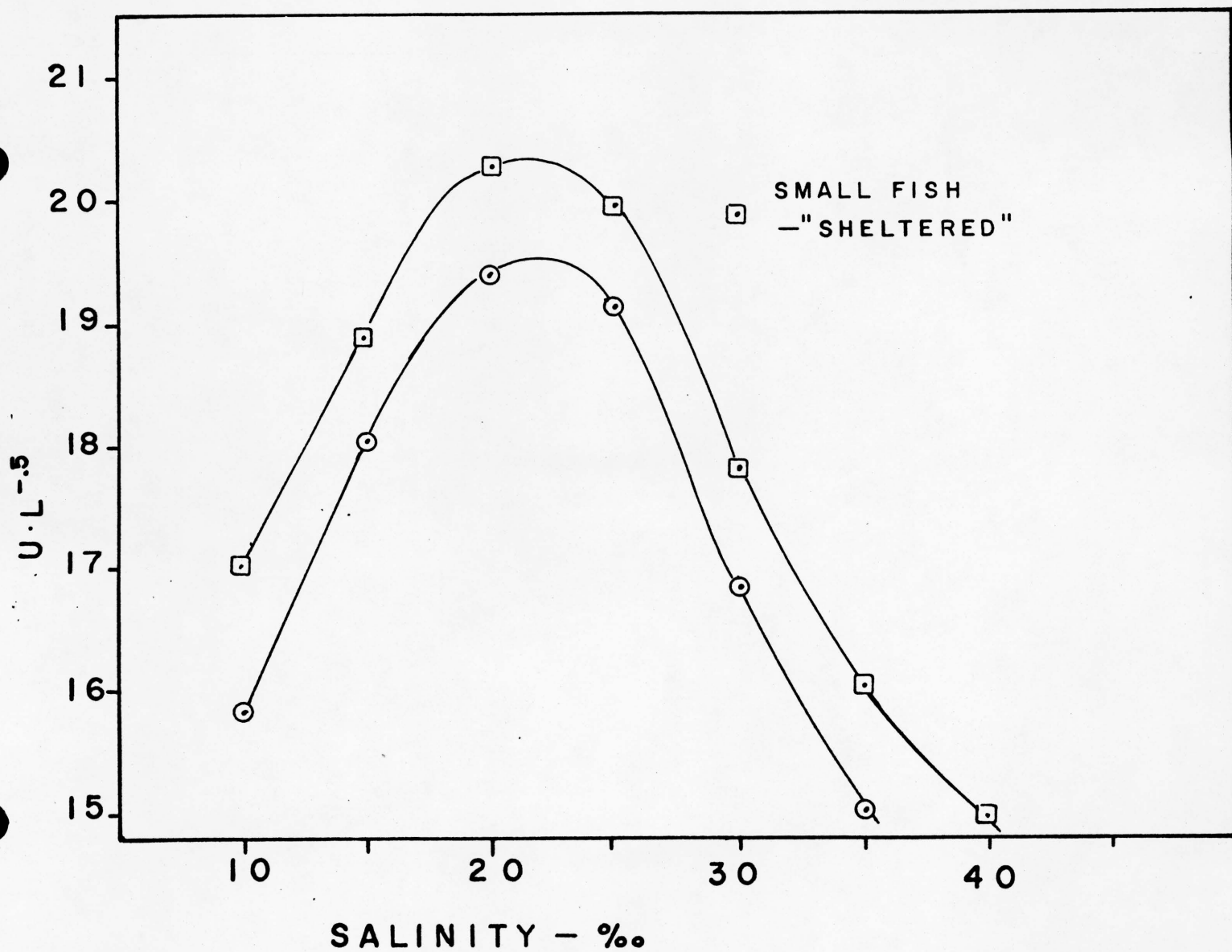
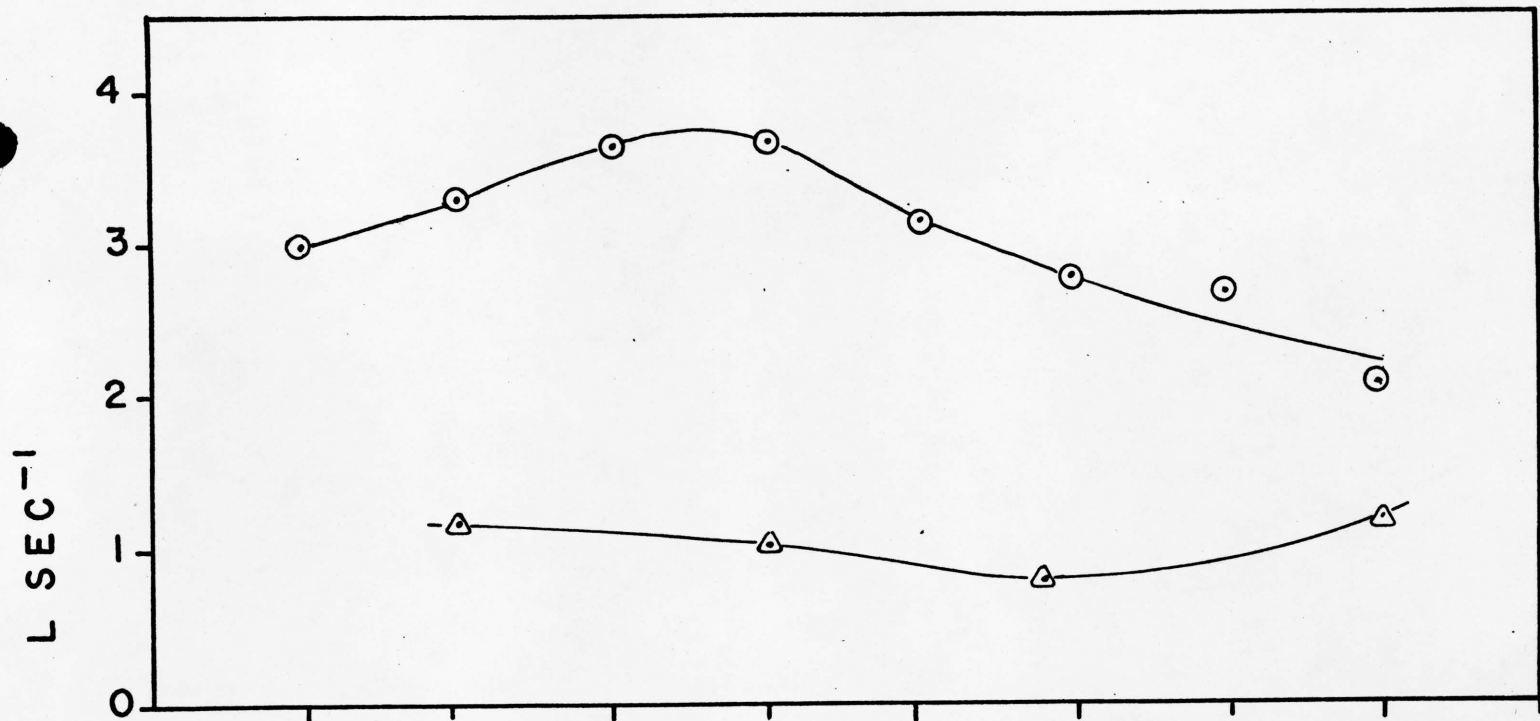


the spotted seatrout. This suggestion is borne out by the fact that the seatrout in the cooling ponds of the Flour Bluff, Texas power plant had a very abundant late summer-early autumn food supply. These fish were much fatter and in far better condition than other fish in the coastal areas at around 28°C and 25-32 ppt, where hypothetically considerable swimming energy would be required just to secure food in addition to assimilating it. While this hypothesis would explain the depressed metabolism and poor condition of the 1975 autumn fish compared to the summer fish used in the Blazka chamber experiments, it is beyond the purview of this study to develop the subject of energetics of feeding, assimilation and growth. It should be emphasized however that fish utilized for initial studies of salinity, temperature and other stress effects should be healthy, growing fish functioning under aerobic metabolic conditions. It would be doubtful that the rather emaciated autumn fish for the Nueces Bay water study at 35 and 45 ppt and 28°C with depressed standard and routine metabolism could have a very high sustained swimming performance rate unless they had propensities for large scale anerobic metabolic processes.

One of the more evident features of the metabolic levels at maximum sustained swimming rates is that the swimming rates also have their maximum values at the optimal salinity around 20 ppt in the same manner as both the metabolic level and scope. In Fig. 4, top panel, the maximum sustained swimming rate is plotted against salinity (upper line) to emphasize this observation. The similar plot for the routine swimming rate (lower

Figure 4. Swimming characteristics of Cynoscion nebulosus at different salinities. Top panel: Swimming speeds in body lengths (cm)  $\text{sec}^{-1}$ ; circles, maximum sustained speeds; triangles, routine speeds. Bottom panel: Swimming speeds in  $\text{cm sec}^{-1}$  (U) divided by square root of length in cm; circles, average maximum values; squares, individual maxima. Note the  $U \cdot L^{-0.5}$  value for one small fish that "sheltered" itself at bottom front of chamber to "block" or reduce effective flow rate far below measured flow rate.





line) does not show the same relationship, although in some but not all of the previous experiments the routine rates also are at a maximum at about 20 ppt salinity.

In Fig. 4, lower panel, the swimming rate as  $U \text{ cm sec}^{-1}$  divided by the square root of fish length in cm shows the same optimum at about 20 ppt both for the averages of the maximum swimming rates (lower line) and for the maximum rates of individual fish at each salinity interval. The single fish at 30 ppt with the "apparent" very high  $U \cdot L^{-0.5}$  that had "sheltered" itself by partially blocking the water flow obviously had a much lower "virtual" swimming rate. One of the great advantages of the Blazka apparatus is that at higher velocities such aberrant behavior is much easier to detect than are corresponding aberrancies at lower velocities in the circular chamber. Also routine rates themselves at constant, but ad libitum, swimming speeds, are more difficult to define.

The behavioral tendencies of the spotted seatrout are admirably suited for the easy recognition and measurement of maximum sustained swimming rates. When the maximum attainable rate is but slightly exceeded, first the fish tend to drift to the back screen gradually and then "burst" slightly to the middle or anterior portion of the tube; then the process tends to be repeated with increasing frequency. Quite likely anaerobic respiration begins at this point.

#### Interpretations of Data Analysis

While the evaluations above establish adequately the optimal salinity at about 20 ppt on several bases, some further evaluations are pertinent to the development of improved analytical techniques.

Once a given species is selected for use in assessing freshwater influx requirements, three major experimental rationales and protocols are suggested. The first involves measurements in the field for a strictly ecological approach. This approach involves technological problems of (a) using respiration chambers in the field, (b) carrying on experiments over extended time and space to gain information over a desired range of temperatures, salinities, etc. and (c) having personnel who can operate and maintain experimental regimes under field conditions; problems of obtaining field-derived standard metabolism data are not easily resolved; and problems of controlling or assessing extraneous natural variability among fish may be difficult, although some of the author's earlier work in polar areas reveals that "uncontrolled" variability is not excessive. The second series of rationales and protocols are those involved in the present field-laboratory study with all the advantages of laboratory controlled conditions, but with considerable disadvantages and costs of obtaining and transporting both water and fish on demand. The third set of considerations involves a strictly physiological, laboratory approach that has both advantages and disadvantages. Advantages are (a) the possibility of having ready access to a stock of experimental fish maintained on tightly controlled regimes, (b) stock fish can be pre-acclimated (or "acclimatized") to experimental conditions far in advance of actual measurements and (c) there can be better control on some, but not necessarily all, variables under study; disadvantages are that (a) decisions on what to control on laboratory stock fish when naturally varying factors (like short term

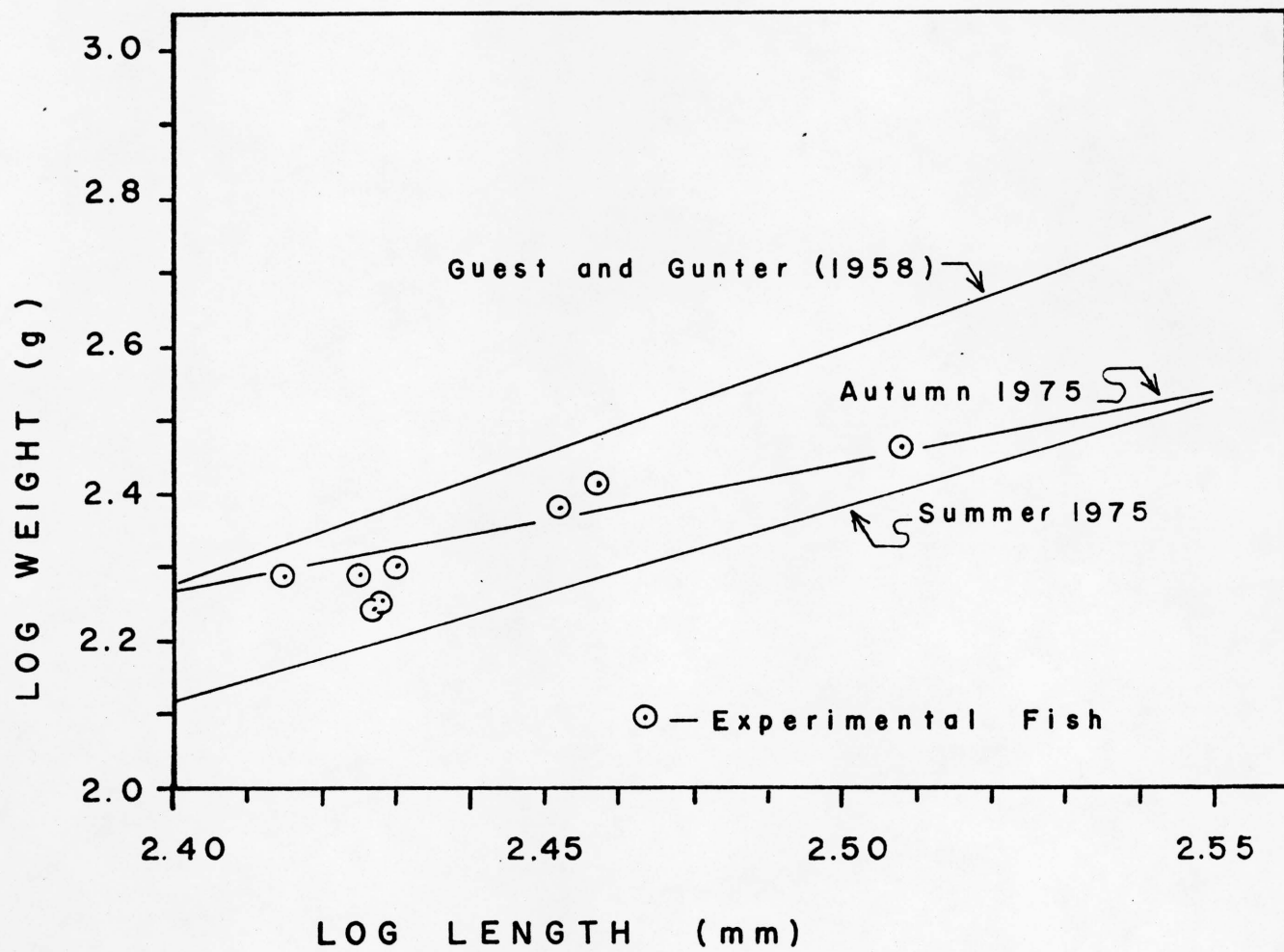
temperature variation, feeding, activity, etc.) are often not easily recognized due to lack of knowledge of natural environmental stress; and (b) there may always be the possibility that laboratory experimental results cannot be directly applied to field conditions.

The need to be apprised of natural variability in the condition of fishes can be illustrated by investigation of the seemingly depressed values of the active metabolic rates at 30 ppt. in the Blazka experiments. Especially critical is the evaluation of the depressed rates that could be expected when fish are in declining physical condition as indicated earlier for the autumn fish in the Nueces Bay experiments. For the several fish used in the maximum swimming rate experiments, it appeared (after the experiments were conducted) that these fish were in poor condition. Compared to the normal Guest and Gunter (1958) data and the autumn and summer regressions of log weight on log length (Table 2), the individuals in maximum swimming rate experiments show a distinct depression in condition in Fig. 5. These weight-length plots compare with the autumn 1975 Nueces Bay experiments, in which the fish were also progressively more emaciated with increasing length.

One of the more important types of critiques for this study involves the use of the linear multiple first order regressions for the estimation of the oxygen consumption in relation to body weight, swimming velocity, salinity and temperature. The coefficients for the body weight seem rather

Figure 5. Log weight -- log length regressions showing relative position of Blazka fish with depressed metabolism at maximum sustained swimming activity (circles) and at 30 ppt. Guest and Gunter (1958) data used for regression for more or less average fish. Autumn 1975 regression from fish in declining condition used in Nueces Bay water experiments; summer 1975 regression data from seawater experiments on relative thin, but healthy, fish.



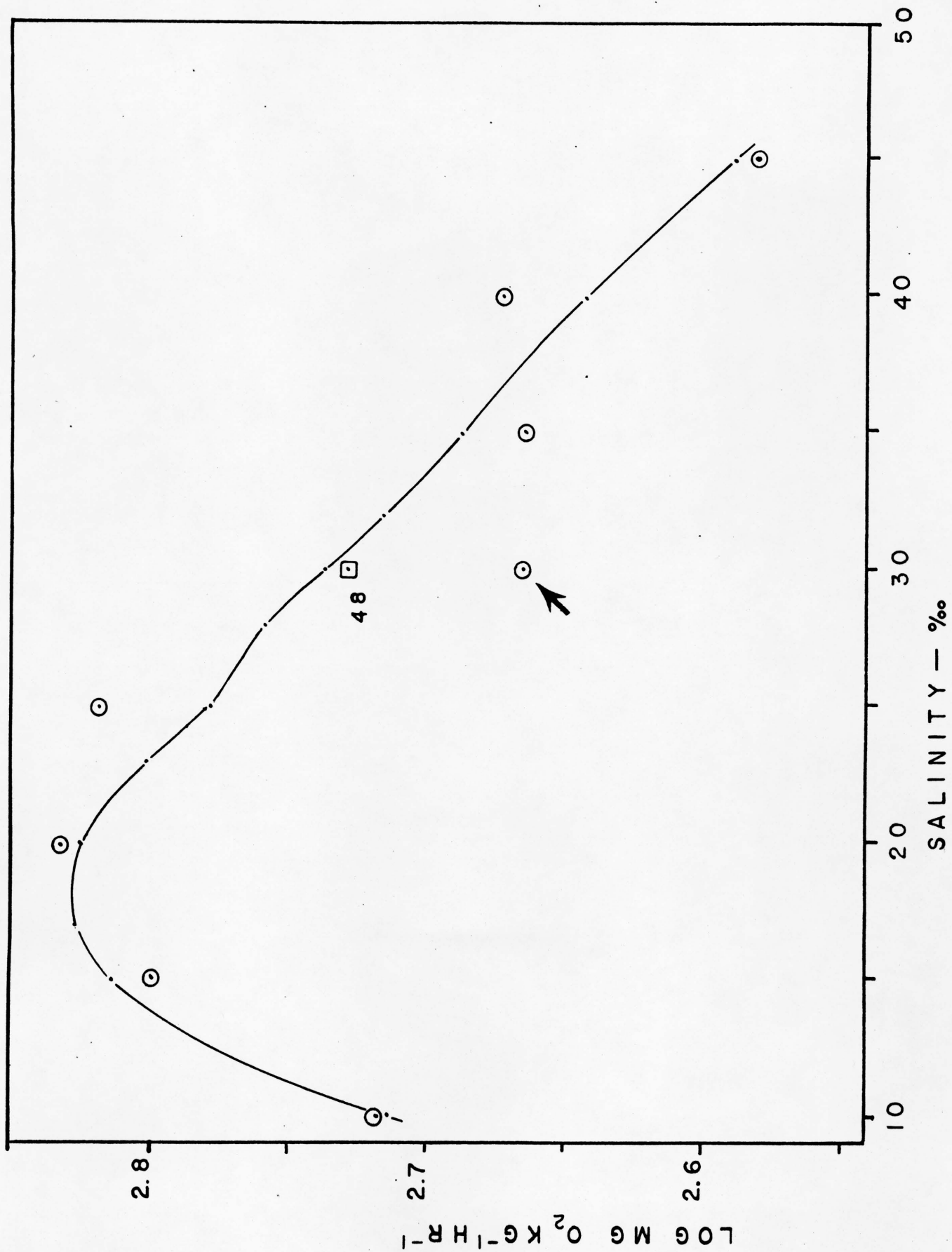


high ( $b_w > 0.8$ ) in many cases and weights are negatively corelated with swimming speed for many of the partial correlations (not tabulated for the individual regressions). These problems have been discussed widely (e.g., Moore 1976; Webb 1975; Griffiths and Alderdice 1972; Fry 1957, 1971; Fry and Cox 1970; Brett 1964, 1965, 1967; and others). Quite obviously a very large actively swimming fish in a small chamber would have its swimming inhibited, but there is also the actuality of correlation between weight (and length) and swimming velocity for hydrodynamic reasons (Webb 1975). For the Blazka chamber experiments in the Fig. 6 comparisons are of interest in comparing observed values from group averages, and values from a fourth order equation (based on the log  $Y \text{ kg}^{-1} \text{ hr}^{-1}$  at maximum  $X_v$ ) in the form:

$$\begin{aligned}\hat{Y} \text{ kg}^{-1} &= a + b_1 X_s + b_2 X_s^2 + b_3 X_s^3 + b_4 X_s^4 \text{ or} \\ \hat{Y} \text{ kg}^{-1} &= 1.9943 + 0.12156 X_s - 6.0960 \times 10^{-3} X_s^2 \\ &\quad + 1.2302 \times 10^{-4} X_s^3 - 9.1230 \times 10^{-7} X_s^4\end{aligned}$$

where  $X_s$  includes the values from 10 to 45 ppt excluding 30 ppt data. Using the variates in the form of  $Y \text{ kg}^{-1}$  for the maximum activity values represents only a part of the information available on weights, salinities and swimming rates, and especially information that may be contained in interactions among these variables. The values calculated from Eqs. 41-48 (Table 15), on the other hand, involve only adjacent salinity (5 ppt) levels (10 ppt in case of Eq. 48), with most of the  $b_s$  salinity coefficients statistically of

Figure 6. Comparisons in "precision" of maximum sustained active metabolic rate calculations in relation to salinity. Encircled points are averages of maximum values from Table 20. Curved line through points calculated by fourth order equation based on all maximum swimming rate data except at 30 ppt. Equation (48) from 25 & 35 ppt from Table 15 is used to calculate value within square at average swimming rate and weight to compare with the depressed observed average value at 30 ppt (arrow).



little interest. Quite obviously what is needed is a multiple regression of a form that could take into account all salinity groupings and all swimming speeds from zero, through routine, and up to the maximum sustained levels. Such an equation and solutions have been suggested by Lindsey and Sandnes (1972) in the nonlinear form of, e.g., a three factor model with a response Y. Such an equation would be

$$Y^C = b_0 + b_1X_1^{a_1} + b_2X_2^{a_2} + b_3X_3^{a_3} + b_4X_1^{2a_1} \\ + b_5X_2^{2a_2} + b_6X_3^{2a_3} + b_7X_1^{a_1} X_2^{a_2} + \\ b_8X_1^{a_1} X_3^{a_3} + b_9X_2^{a_2} X_3^{a_3}.$$

This equation could relate oxygen consumption rate Y to power c and to independent variables  $X_1$ ,  $X_2$ ,  $X_3$  (like body weight, salinity and swimming speed) with respective powers  $a_1$ ,  $a_2$  and  $a_3$  and the quadratic  $2a_1$ ,  $2a_2$  and  $2a_3$ , and the partial regression coefficients  $b_1$  to  $b_9$  for each of the single factor and cross products terms. Statistically significant coefficients  $b_7$ ,  $b_8$ , and  $b_9$  for the cross product terms would indicate interactions among  $X_1$ ,  $X_2$  and  $X_3$ . Griffiths and Alderdice (1972) give an example. The statistical efficiency of such a nonlinear equation is far greater than the salinity range-limited linear regressions, used in this study or in the linear form suggested by, e.g., the cubic equation above.

The nonlinear exponential equation suggested above would enable use of oxygen consumption rate and weight in linear



units instead of log units (as in this study) and salinity, swimming velocity and temperature in the usual units. It could be applied also to the standard oxygen consumption rates for a second equation. Scope for activity could then be calculated directly by difference in  $y_{\text{active}}^c$  and  $y_{\text{standard}}^c$ .

There are some pointed suggestions in the literature to the effect that measuring the swimming in units of speed (e.g.,  $U \text{ cm sec}^{-1}$ ) and in units of body lengths (e.g.,  $L \text{ sec}^{-1}$  as in this study) does not adequately describe swimming characteristics on hydrodynamical grounds.

The rationale of using swimming velocity divided by the square root of length as for the experiments for higher swimming velocities has some important implications. In comparing swimming rates of different sized fishes, some sort of consideration should be made of the fact that for, a given species, larger fish can swim faster than smaller fish. Many studies, including this study, utilize the "specific" swimming velocity of  $L \text{ sec}^{-1}$  instead of simply "swimming speed" of  $L \text{ sec}^{-1}$  also tends to diminish with increasing length when size ranges are large. In general, maximum sustained swimming speeds for fishes is proportional to  $L^{0.5}$  to  $L^{0.6}$ . Jones (1971) suggests that velocity in both trout and salmon is proportional to the square root of length, which can be shown to have a theoretical basis in the Lambert-Teissier theory of biological similarity.

From this theory, power is proportional to  $L^{2.3}$  when Gunther's (1975) empirical correction factor is used. According to the standard hydrodynamical equation, drag is

proportional to  $L^{1.8}$ . Since, by dimensional analysis, velocity is proportional to power divided by drag, velocity would be expected to be  $L^{2.3}/L^{1.8} = L^{0.5}$ . Brett (1967) notes that in some species the relative body musculature increases with size (to produce "lunker" fish), in which case the exponent would be somewhat larger than 0.5. Because the spotted seatrout in this study do not suggest that body musculature has a relative increase with size, the use of  $U \cdot \sqrt{L}$  to compare swimming performances as in Table 20 and Fig. 4 appears justified.

In summary the interpretations of the results in future metabolic studies of this type can probably be carried out better with curvilinear exponential, instead of linear first-order, multiple regressions using the same independent variables of weight, temperature and salinity measurements. However, there can probably be improvements in the use of the specific swimming velocity ( $L \text{ sec}^{-1}$ ) by substituting  $U \cdot L^{0.5}$  or a similar function.

## CONCLUSIONS

1. For both the scope for routine activity and the scope for maximum sustained activity, the maximum is at about 20 ppt salinity for the spotted seatrout.
2. When normal fish are subject to salinity stress above or below 20 ppt the levels of routine metabolism should minimally be about twice the standard rates to allow for feeding and growth.
3. In the south Texas coastal area in late summer some fishes, including seatrout, apparently experience growth rate declines and weight losses. The larger the spotted seatrout, the relatively greater were their weight losses in October-November. The rather emaciated spotted seatrout at this time had depressed routine and standard metabolism. Fish in poor condition should not be used for assessing freshwater influx effects unless a concomitant comparative study of normally growing fish is available.
4. At late autumn and winter temperatures, the maximum scope for sea waters tested at various salinities is about 20 ppt. There is no evident seasonal shift in the salinity optimum.
5. At winter temperatures, there is some evidence that routine scope is fairly high and that positive cold adaptation is suggested, even though routine swimming rates are lower at low temperatures.
6. Ad libitum routine swimming rates tend to be low enough at winter temperatures to suggest that more useful scope measurements be based on metabolic rates at least approaching maximum sustained rates.

7. Series of 1976 experiments from winter to summer on San Antonio, Lavaca and Nueces Bay waters at various salinities and temperatures yield routine scope measurements that are of the same comparable order as those for seawaters, which implies that there were no extraneous stresses as were suggested for the Nueces Bay waters in summer 1975.
8. The use of metabolic rates at maximum sustained swimming rates by use of the Blazka respirometer compared to standard rates yield more definitive maximum scope values for salinity evaluations than routine scope values.
9. The metabolic levels at maximum sustained swimming rates either may be averaged or the largest single rate at each salinity may be used for scope estimation.
10. While routine swimming rates themselves may or may not be related to the 20 ppt optimal salinity, the maximum sustained swimming rates definitely are. At various salinities, either the averages of maximum sustained rates or the highest rates for individual fish will be maximal at about 20 ppt. Swimming rates may be conveniently expressed as lengths per second or as centimeters per second divided by the square root of the lengths.
11. The field-laboratory techniques used in this study are discussed in terms of precision and costs, compared to ecologically oriented studies confined to the field and to physiologically oriented studies confined to laboratory-maintained fish stocks. If the environmental or ecological viewpoint is unimportant in assessing freshwater influx effects, laboratory oriented

experiments might be less costly and would avoid environmental problems (a) with experiments on fish of variable conditions and health and (b) with different waters that may have stressful pollutants. (However, "indoor" experiments would be of no use in identifying environmental problems (a) and (b)!!)

12. Some major "improvements" are suggested for the statistical treatment of data, especially at the levels of maximum sustained activity. They include analysis of data based on curvilinear higher order equations and on exponential multivariate forms with cross product (interaction) terms.

Since there may be a fish size-swimming speed correlation, better methods that utilize hydrodynamical considerations for assessing swimming speed are suggested.

13. Summary Figure Illustrating Metabolic Level and Salinity Relationships —

Much of the 24-28°C data over various salinities and in water from several sources can be summarized in Fig. 7. The vertical heights of the lines at the first level are standard rates (heavy stippling), at the second level are the routine swimming rates (light stippling), and at the third level for the seawater series at the left are the maximum sustained rates (clear). The tops of the vertical lines are connected to show trends for the seawater data. Note the depression at 30 ppt salinity for the seawater data in left figure. The dashed lines that connect various vertical lines at selected salinities for data from waters of Nueces, San Antonio and Lavaca Bays do not show trends in the appended Figure 7.



# ACTIVE, ROUTINE, AND STANDARD METABOLISM

*Cynoscion nebulosus*

24 - 28° C

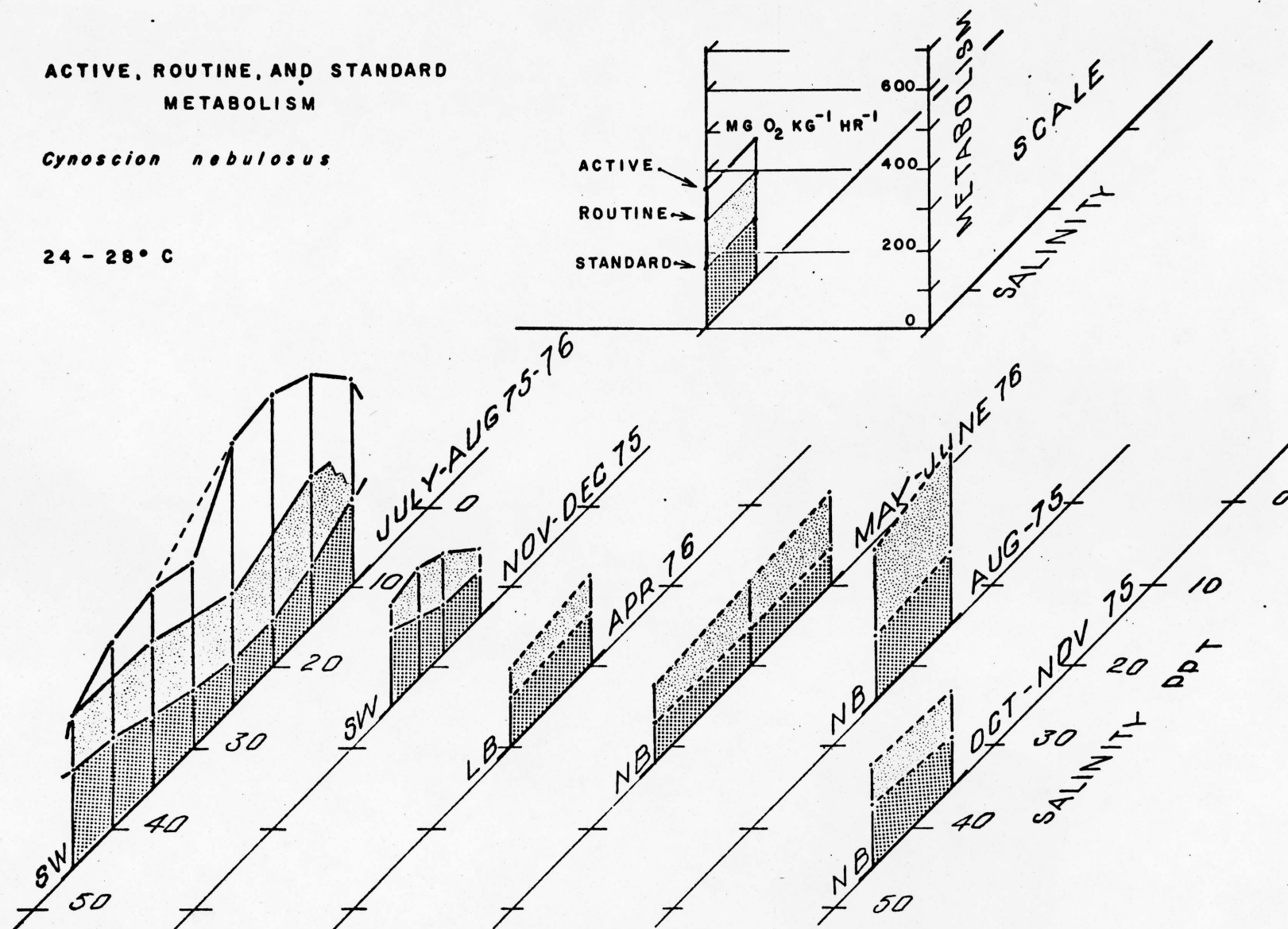


Figure 7. Summary

## ACKNOWLEDGMENTS

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