Research Technical Completion Report

ASSESSING HABITAT SUITABILITY FOR WALLEYE *(Stizostedion vitreum)* AND POSSIBLE SPECIES INTERACTION WITH SALMONID FISHES

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ABSTRACT

Sports fishermen throughout North America are pressuring fisheries management agencies to introduce exotic fishes. Few techniques are available, however, to assess the suitability of the habitat and the potential for adverse effects. The objectives of this study were: (1) to develop a methodology to predict the probability of successfully establishing an exotic species of fish; (2) to develop a predictive model; and (3) to apply a technique for an ecological analysis of a hypothetical system to assess possible interactions between species. We selected walleye (Stizostedion vitreum) as our target exotic species because of increasing interest to introduce this species into waters throughout Idaho and other states in the Pacific Northwest.

Fifty state and provincial fisheries management agencies responded to our survey about their success of establishing self-reproducing populations of walleye. Responses suggested an average success rate to establish walleye of 35%. From this survey, we identified 542 lakes where walleye were planted and acquired water quality and morphometric data from 293 of these lakes. Comparisons of these variables between lakes classified as successful or unsuccessful demonstrated 12 of 17 variables were significantly ($P < 0.05$) higher in successful waters than in unsuccessful waters. Correlation analysis was used to determine associations between variables, and Model II

regressions were performed to complete the selection data set of 29 lakes. A stepwise discriminant analysis was conducted using 13 variables; after five steps in the analysis, the variables area, maximum depth, pH and date of dam closure were selected. A second discriminant analysis computed the value of the discriminant functions. Although the average squared canonical correlation suggested a 77% predictive capability, classification of a sample data set indicated that 74.6% of the lakes were classified correctly. To simplify use of this information, the discriminant coefficients were incorporated into a fortran program.

Loop analysis was applied to four scenarios using walleye as a predator. When walleye were introduced into a system with a salmonid predator (e.g. chinook salmon - Oncorhynchus tshawytscha) and prey (kokanee - O. nerka) and walleye consumed individuals of both species, loop analysis indicated an unstable system would result. A second scenario of walleye and a salmonid predator competing for the same prey also resulted in an unstable system. When walleye and a salmonid predator consumed an abundant prey base or when walleye were introduced with two prey species, a stable system was predicted. Results of the loop and discriminant analyses corroborate field observations and literature information.

INTRODUCTION

Introductions of fish outside their native ranges (exotics) result in a number of changes in the receiving ecosystem (Magnuson 1976). Increased emigration and extinction rates in resident fishes are two changes that can occur. Introduced species induce increased instability in community structure which adds further uncertainty to the validity of management plans which utilize exotic fishes. Many state fisheries management programs, however, are based on management of exotic fishes. For example, the State of Idaho has 67 species of fish, 39 are native, while the remaining 28 were introduced (Simpson and Wallace 1978). Although not all of the introduced species are of sporting interest, the proportion of native to non-native fishes is even higher in some states. Unfortunately, sportsmen groups often pressure management agencies to introduce exotics and base their management programs to a large extent on exotic fishes.

Historically, Idaho has provided mainly coldwater sport fishing opportunities. However, interest in cool and warmwater fisheries appears to be expanding. By means of a petition and personal contact to the Department of Fish and Game in 1983, sport fishermen expressed interest in expanding Idaho's coolwater fishery resources. This desire for expansion of sport fishing opportunities was partly a result of perceived successes in neighboring states to establish fishable populations of walleye, Stizostedion vitreum vitreum (Mitchell 1818). Although more Idaho fishermen prefer trout (Gordon 1970), reservoir construction projects and immigration of people from the midwest augment public pressures to expand warm and cool water fisheries. Walleye, although only marginally noted for their sporting qualities, are highly prized as a food fish as a result of their superb flaky white meat and large size (Scott and Crossman 1973).

Walleye were first reported in Idaho in 1951 by creel census personnel at Lake Pend Oreille (Simpson and Wallace 1978) but no further reports were received in the state until 1975. The next occurrence of walleye resulted from efforts by the Idaho Department of Fish and Game in planting them in 1974 in Mud Lake and Salmon Falls Reservoir. After subsequent stocking in Salmon Falls Reservoir and two introductory stockings in Onieda Reservoir, also in southern Idaho, viable reproducing populations were established. At present, the Idaho state record for walleye exceeds 11 pounds from Salmon Falls Reservoir (Bob Bell, personal communication, Idaho Department of Fish and Game). To date, however, no reproducing population has been established in Mud Lake but the cause is not known.

Walleye stocks also have been successfully established in other parts of the Pacific Northwest. With the illegal introduction of walleye above Grand Coulee Dam into Lake Roosevelt, presumably by sportsmen sometime during the 1940's and 1950's, subsequent distribution of this species has occurred downstream in the Columbia River and into the Snake River system (Neilsen 1975). The resultant fisheries have been regarded as successful by sports fishermen. For example, the Lake Roosevelt fishery in 1980 had a catch rate of 0.51 walleye per hour and fish exibited good growth of 20.6 inches (52.3 cm) within 5 years (Harper et al. 1980).

With development of a successful walleye fishery in Lake Roosevelt, additional pressures are being placed on fishery management personnel in northwestern states to stock walleye. Recently, the Lake Roosevelt fishery has become popular with northern Idaho fishermen. Successful fishing trips have made anglers question the disproportionately high expenditures on managing salmonid fisheries. Added incentives to establish a walleye fishery in northern Idaho were the long distances to walleye fisheries in southern Idaho. Also, the need to leave the state and purchase an out of state fishing license for a fish that Idaho waters might support was probably a source of additional pressures.

In response to this public pressure, two questions should be considered. The first question relates to economics. In over a century of stocking walleyes with less than half of that time spent on evaluations, the result of those stockings have varied along a continuum of success to failure. An average of 48% success has occurred from introductory stockings where walleye were originally absent (Laarman 1978). Thus, at present, making a projection of which new bodies of water could be successfully stocked with walleyes is less than even odds. The states of Ohio (Erickson and Stevenson 1972) and Wisconsin reported survival rates ranged from 0 to 14% when stocking fingerlings (Anonymous 1968). The question of where introductions will be successful has an added economic basis in the northwest because the rearing and propagating of walleyes differ widely from the aquaculture techniques used for salmonids. Concrete raceways and manufactured feeds for salmonids do not lend themselves to raising walleye, so unless new facilities are developed, stocking programs must depend on other states for fry or fingerlings.

One method to answer the question of where introductory stockings will be successful in establishing self-reproducing populations is building a predictive model. Predictive models are usually based on some aspect of the life history as was developed in Texas (Prentice and Clark 1978). Their model, WALLEYE, is based on three parameters crucial for walleye success in Texas: (1) water temperature during the spawning season; (2) availability of suitable spawning sites which determine the reproductive success; and, (3) the standing crop of potential predators. This model, however, is not appropriate for waters in northern latitudes because warm winter temperatures in Texas that preclude gonadal development in walleyes would not be the limiting factor in cooler climates (Clark 1980). As a result, the biological and social problems of where to stock walleye in northern areas of the United States remain.

The second question to consider in Idaho is that since walleye are a top predator and usually not preyed on by other fishes, could walleye have a detrimental interaction on anadromous and resident salmonid fisheries? Case studies of interactions when walleye coexist with salmonids are rare since most state fishery agencies have avoided placing the two in sympatry (Bennett 1979). In a few Wyoming reservoirs, intense competition and predation by walleye with stocked salmonids have required a complete revision of fisheries management plans (J.R White, Wyoming Game and Fish, personal communication). Also, Gray et al. (1983) reported a frequency of occurrence of 42% of juvenile anadromous salmonids in the stomachs of walleyes collected in the John Day (Columbia River) tailrace during spring. Other studies have found few salmonids were eaten by walleyes (Maule 1982). The magnitude of predation is difficult to assess, however, because no estimates of walleye population size have been available. Others like Colby et al. (1979) believe that salmonids and walleye can coexist in sympatry.

Therefore, the lack of any tool to predict the success of an exotic introduction and the interaction of the introduced species on resident or native species led to the development of this project. The ojectives are:

(1)To develop a method to predict the success of establishing non-native fish populations;

(2)To develop a predictive model for walleyes where selected waters could be entered to evaluate the probability of the introduction resulting in a viable reproducing population;

(3)To apply this model to representative waters in southern, eastern, and northern Idaho and assess their potential for establishing fishable walleye populations; and,

(4)To apply a technique such as loop analysis for an ecological analysis of a body of water to help in the prediction of possible interactions between salmonids and walleye.

The methodology developed in this study, although focusing on walleye as a target species, could be applied to other target species (northern pike, striped bass, lake trout, smallmouth bass, etc.) which might be under consideration by management agencies for future stockings.

METHODS

We reviewed the literature and developed a list of limnological parameters associated with the success of walleye populations in North American waters. In development of this list the following relationships were taken into account: (1) walleyes appear to reach their highest abundance in large, shallow, turbid lakes (Scott and Crossman 1973); (2) an increase in abundance and growth occurs when walleye populations partition the mesotrophic portions of large lakes of disparate environments, ranging from eutrophic to morphometrically oligotrophic (Schupp 1978); (3) lakes with a lower shoreline development factor support higher walleye populations than lakes having higher shoreline development factors (Johnson and Hale 1963); (4) walleye may occur in post-glacial oligotrophic lakes where sufficient littoral environment occurs or where cultural eutrophication has or is occurring (Kitchell et al. 1977); (5) walleyes are normally found at depths of 1-15 m unless insufficient shelter, turbidity, or color exist in which case they can be found to depths of 27 m (Regier et al. 1969); (6) dissolved solids are tolerated to 15,000 mg/liter with the optimum being 40-80 mg/liter (Regier et al. 1969); (7) light is the most important factor in determining the diurnal distribution because of the presence of a tapetum lucidum in the retina of the eye (Moore 1944) which makes the walleye negatively phototactic (Scherer

1976); and, (8) the density of Daphnia or other zooplankton and water temperature at the time of hatching affect survival and year class strength (Koenst and Smith 1976).

To develop a method to predict the success of establishing walleye, we identified where walleye have been stocked in North America and the success of that introduction. We developed a written questionnaire that was sent to all state and provincial fish and game agencies in the continental United States and Canada (Appendix A-1). The survey solicited responses to the following questions:

(1) Has your state introduced walleye into bodies of water where this species was not previously reported?

(2) Did this introductory stocking or subsequent stocking result in a reproducing population?

(3) What was the approximate percent success rate?

(4) Please send a list of lakes and reservoirs stocked with walleye, and indicate which ones have a self-sustaining population as a result of stocking. Please note that those deemed unsuccessful are as important as those deemed successful.

(5) Would you like a copy of the results?

If a response were not received in one month a subsequent letter was then sent and followed with a telephone call to the particular agency.

From the results of our questionnaire survey (question #4), a list of waters was compiled relative to the successful or unsuccessful establishment of walleye (Appendix A-2). The criterion used for successful establishment was whether the population was self-sustaining by reproduction.

Once the water bodies were identified, the appropriate state water resource agencies were contacted to obtain their National Eutrophication Survey Reports (305b) and Clean Lakes Reports for the necessary water quality and morphometric data (Appendix A-3).

Most states had not completed these reports and more efficient means of obtaining these data were required. Contacts were made to regional offices of the Environmental Protection Agency (EPA). EPA personnel recommended accessing the data via the national water quality data bank. However, costs were deemed prohibitive (>$500.00/hour) as most regional offices charged for this service. To minimize costs, a computer account was established with the National Computer Center (NCC) at Triangle Park, North Carolina to gain access to the EPA data base, STORET. Further contact with EPA and state water quality agencies was necessary to obtain water quality station numbers and agency codes. Communication with the national computer system to obtain water quality data was accomplished from the University of Idaho with the use of an International Business Machine (IBM) personal computer and printer coupled to a Hayes Smart-Modem with appropriate asynchronous communication software to access the program mean on the NCC STORET system.

Water quality and morphometric parameters selected for statistical analysis were based on the literature review and discussion with fishery and water quality specialists. The following data were requested from lakes and reservoirs where walleye were known to have been stocked: (1) surface area; (2) mean depth; (3) maximum depth; (4) elevation; (5) year of impoundment of the reservoir; (6) secchi disk transparency; (7) chlorophyll 'a'; (8) total nitrogen; (9) total phosphorus; (10) total hardness; (11) hydrogen sulfide; (12) pH; (13) specific conductance; (14) sodium level; (15) sulfates; (16) color; (17) turbidity; (18) total dissolved solids; (19) total alkalinity; (20) chloride content; (21) iron content; and, (22) potassium concentration.

Data obtained from various water quality reports and the NCC system were entered on an IBM 4341 computer at the University of Idaho. Initially, a test for normality of the data was performed using the Statistical Analysis System (SAS) UNIVARIATE procedure. After this analysis, transformations were made (Appendix A-4) to satisfy the assumptions of normality. A correlation analysis on all variables was performed using SAS. From these results, Model II regressions (Sokal and Rohlf 1969) were conducted to generate missing values where a significant correlation existed ($r>0.87$ and $P<0.0001$). The normalized data set was then subjected to a stepwise discriminant analysis using SAS (STEPDISC) to determine which parameters can contribute to the successful habitation of walleye in an ecosystem (Morrison 1976). Following the selection of these significant parameters ($P<0.01$) with the stepwise discriminant analysis, another discriminant analysis was performed on the complete data set using the SAS procedure DISCRIM to obtain the overall relative efficiency and discriminant function coefficients.

For added discriminating power, we tested the homogeneity of the within covariance matrices (successful and unsuccessful reservoirs) using the following method:

NOTATION:

K	=	Number of Groups
P	=	Number of Variables
N	=	Total Number of Observations
N(I)	=	Number of Observations in the I'th Group
DF	=	Degrees of Freedom

$$V = \frac{\prod |\text{WITHIN SS MATRIX}(I)|^{N(I)/2}}{|\text{POOLED SS MATRIX}|^{N/2}}$$

$$RHO = 1.0 - \left[\text{SUM} \frac{1}{N(I)-1} - \frac{1}{N-K} \right] \frac{2P^2 + 3P - 1}{6(P+1)(K-1)}$$

$$DF = .5(K-1)P(P+1)$$

Under the Null Hypothesis:

$$-2\ RHO\ LN \left[\frac{N^{PN/2}\ V}{\prod N(I)^{PN(I)/2}} \right]$$

A FORTRAN model was developed based on the discriminant functions to predict the probability of success or failure of establishing reproducing populations of walleye in a given body of water. Input into the model are values for various limnological variables found significant by the discriminant analysis.

Loop analysis was applied as a method to predict ecosystem behavior in response to an introduced species. Specifically, loop analysis was applied to gain insight into possible interactions which might occur if walleye were introduced into a system. The advantages of loop analysis are that it does not need any quantified variables or connections between them (Puccia 1983). The user needs to provide information whether a given species is helped, harmed, or not affected by the introduction of another species into the community (for detailed derivation of loop analysis, see Levins 1974, 1975; Lane and Levins 1977). As a result of the lack of information on the interaction between salmonids and walleye, the analysis was performed using a variety of hypothetical situations pertinent to Idaho waters to determine whether the ecosystem would go towards stability or instability. Also, loop analysis estimates at what level of interaction the system would become unstable. The testing of stability at system levels was accomplished by use of the equation (Levins 1975):

$$F_k = \Sigma (-1)^{m+1} L(m,k)$$

where: L(m,k) is the product of k links which form m disjunct loops.

If the result of this equation were negative for any F_k then the system is unstable at the k level. A second test for system stability, the Ruth-Hurwitz theorem ($F_1F_2+F_3>0$) was conducted on the various senerios. The generalized three level case is shown in Figure 1a.

The algebraic expansion equations for the generalized three level case five that F_k is the determinant of the order k and where L(m,k) is a product of m disjunct loops totaling k elements. The algebraic sums for each level are as follows:

$$F_1 = -(a_{11}+ a_{22}+ a_{33})$$

$$F_2 = (a_{12}a_{21})+(a_{23}a_{32})+(a_{13}a_{31}) -(a_{11}a_{22})-(a_{11}a_{33})-(a_{22}a_{33})$$

$$F_3 = (a_{11}a_{22}a_{33})-(a_{11}a_{23}a_{32})-(a_{12}a_{21}a_{33})\ {}_{33}) +(a_{12}a_{23}a_{31})+(a_{13}a_{21}a_{32})-(a_{13}a_{22}a_{31})$$

The algebraic expansion of the Routh-Hurwitz criterion is shown below:

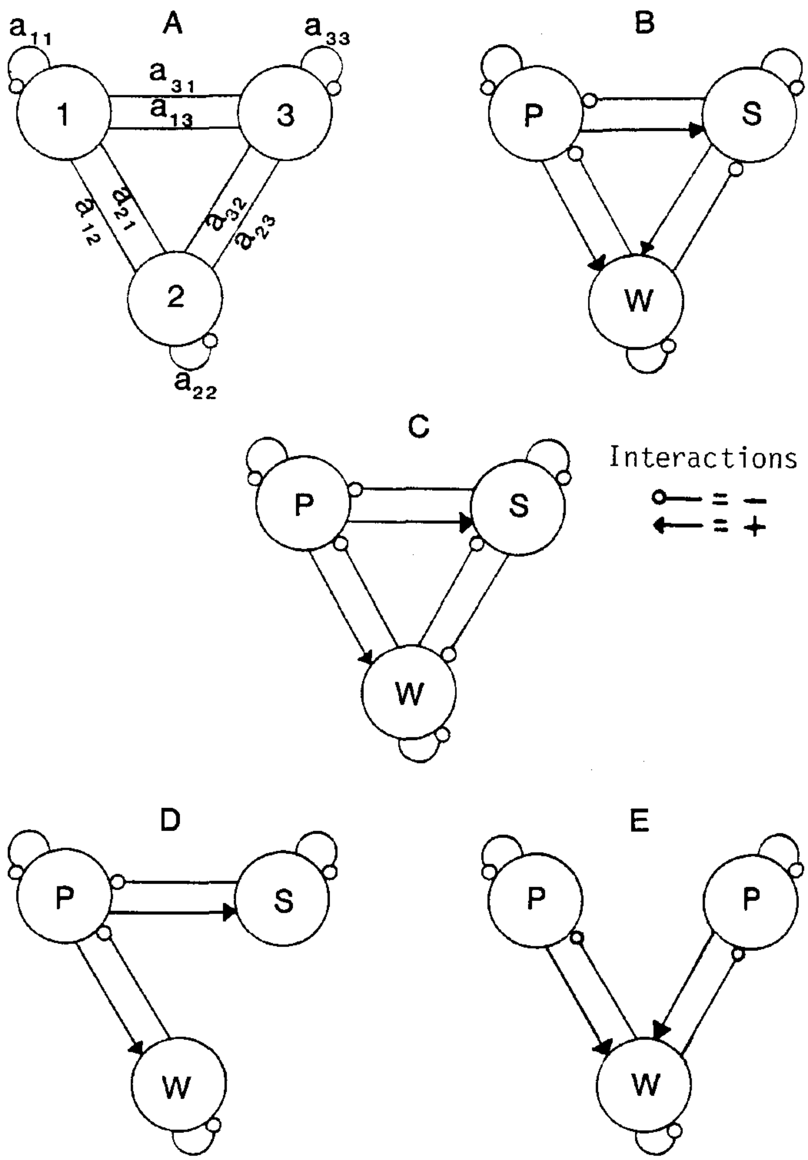

Figure 1. Scenarios using loop analysis to assess species interactions. Shown are the generalized case (A), walleye (W) feeding on a prey (P) and a salmonid (S) predator (B), walleye in competition for prey with a salmonid predator (C), walleye and a salmonid predator feeding on an abundant prey, thus no competition (D), and walleye feeding on individuals of two prey species (E).

$$
\begin{aligned}
(F_1F_2)+F_3 = {} & (a_{11}a_{12}a_{21})+(a_{11}a_{13}a_{31})+(a_{11}a_{23}a_{32})+(a_{11}^2a_{22})+ \\
& (a_{11}^2a_{33})+(a_{11}a_{22}a_{33})+(a_{22}a_{12}a_{21})+(a_{22}a_{13}a_{31})+ \\
& (a_{22}a_{23}a_{32})+(a_{11}a_{22}^2)+(a_{11}a_{22}a_{33})+(a_{22}^2a_{33})+ \\
& (a_{33}a_{12}a_{21})+(a_{33}a_{13}a_{31})+(a_{33}a_{23}a_{32})+(a_{11}a_{22}a_{33})+ \\
& (a_{11}a_{33}^2)+(a_{22}a_{33}^2)-(a_{12}a_{31}a_{23})-(a_{21}a_{32}a_{31})- \\
& (a_{11}a_{23}a_{32})-(a_{22}a_{31}a_{13})-(a_{33}a_{12}a_{21})-(a_{11}a_{22}a_{33})
\end{aligned}
$$

RESULTS

Questionnaire Survey

Fifty of 58 state and provincial fisheries agencies responded to our survey questionnaire (Table 1). Of those agencies returning the questionnaire, 86.0% (n=43) had made introductory stockings of walleye. Almost 57% (n=29) of the agencies indicated that an introductory or subsequent stocking resulted in reproducing populations. Based on the questionnaire survey, the approximate success rate for establishing a reproducing walleye population was 35.29% of all lakes planted. From the questionnaire (question 4), we identified 542 lakes where walleye were planted (Appendix A-2), 44% were classified as successful.

Water quality and morphometric data were acquired for 293 lakes. Canadian lakes were omitted because of time constraints. First, we found significant differences between means of variables from successful and unsuccessful waters (Table 2). Means of 12 of 17 variables were significantly ($P < 0.05$) higher than those from unsuccessful waters. Next, a correlation analysis (Table 3) was performed to find associations between variables. The data set was completed with the use of the Type II equations (Appendix A-5).

Table 1. Results of survey questionnaire to state and provincial fisheries management agencies.

QUESTION 1

Has your state introduced walleye into bodies of water where this species was not previously reported?

Response	Frequency	Cum Freq	Percent	Cum Percent
Yes	44	44	86.275	86.274
No	7	51	13.725	100.000

QUESTION 2

Did this introductory stocking or subsequent stocking result in a reproducing population?

Response	Frequency	Cum Freq	Percent	Cum Percent
Yes	29	29	56.863	56.863
No	13	42	25.490	82.353
n/a	7	49	13.725	96.078
Blank	2	51	3.922	100.000

QUESTION 3

What was the approximate percent success rate?

	N	Mean	Minimum value	Maximum value	Std error of mean
% success	30	35.29032258	0	100	7.023990

Response	Frequency	Cum Freq	Percent	Cum Percent
Uncertain	4	4	19.048	19.048
n/a	7	11	33.333	52.381
Blank	10	21	47.619	100.000

QUESTION 4

Please send a list of lakes and reservoirs stocked with walleye, and indicate which ones have a self-sustaining population as a result of stocking. Please note that those unsuccessful are as important as those deemed successful.

Lakes	Frequency	Cum Freq	Percent	Cum Percent
Successful	180	180	61.433	61.433
Unsuccessful	113	293	38.567	100.000

QUESTION 5

Would you like a copy of the results?

Response	Frequency	Cum Freq	Percent	Cum Percent
Yes	43	43	84.314	84.314
No	8	51	15.686	100.000

Table 2. Comparison of the means (t) and variances (F) for the variables from waters that were successfully planted with walleye vs. those that were unsuccessful. Statistical comparison of means and variances was conducted on transformed variables (Appendix A-4).

	LAKE CLASSIFICATION							
	Successful			Unsuccessful				
Variable	Mean	N	Std. Error	Mean	N	Std. Error	t	F
Area	12728.4	101	2241.21	4515.1	116	1046.51	6.97	1.82
Maximum Depth	110.4	81	10.96	65.9	87	8.06	5.54	1.16
Elevation	2456.9	68	190.79	1745.9	71	214.46	3.74	2.21
Reservoir Closure	1945.8	73	2.03	1949.4	63	2.01	-1.23	1.19
pH	7.9	71	0.07	7.6	57	0.09	2.63	1.41
Alkalinity	150.9	61	10.97	109.3	58	11.93	3.06	1.49
Phosphorus	0.19	29	0.050	0.13	35	0.028	1.10	1.07
Nitrogen	0.91	19	0.143	0.82	29	0.132	1.11	7.96
Hardness	233.5	70	30.26	157.7	57	24.99	2.47	1.22
Turbidity	21.1	49	6.06	24.0	49	3.85	-0.74	1.06
Chlorophyll A	15.9	45	3.10	14.4	34	2.27	-1.19	2.59
TDS	457.6	59	36.06	329.4	50	33.92	2.95	1.01
Field Conductance	568.7	70	5.48	357.7	57	45.81	2.53	1.73
Color	21.1	10	0.341	19.6	12	3.79	-0.28	1.82
Sulfates	196.6	62	37.12	157.6	49	51.57	1.91	1.05
Calcium	51.3	70	7.69	33.7	57	3.96	2.53	1.15
Chloride	59.4	63	16.40	37.3	48	9.50	1.34	1.10
Sodium	143.4	43	22.00	101.2	32	33.23	3.34	2.11
Potassium	6.1	18	1.15	3.1	21	0.57	2.68	1.17
Secchi Disk	107.9	53	34.05	67.3	43	7.81	0.67	1.77
Lab. Conductance	758.6	62	109.51	502.2	52	117.50	2.14	1.55

t-test from comparison of means (successful vs. unsuccessful)

F-test for homogeneity of variances

Table 3. Correlation matrix for various water quality variables. The strength of association (r) and level of significance (P) are shown (r/P).

Variable	Hardness	TDS	Conduct	Sulfates	Calcium	Chloride	Sodium	LCond'
HARDNESS	1.00000 0.0000	0.81612 0.0001	0.96041 0.0001	0.86401 0.0001	0.85017 0.0001	0.75167 0.0001	0.89227 0.0001	0.93988 0.0001
TDS	0.81612 0.0001	1.00000 0.0000	0.94168 0.0001	0.53688 0.0391	0.76115 0.0040	0.24215 0.4254	0.65831 0.0199	0.87433 0.0002
CONDUCT	0.96041 0.0001	0.94168 0.0001	1.00000 0.0000	0.87486 0.0001	0.94050 0.0001	0.89049 0.0001	0.91728 0.0001	0.96137 0.0001
SULFATES	0.86401 0.0001	0.53688 0.0391	0.87486 0.0001	1.00000 0.0000	0.61293 0.0001	0.47530 0.0002	0.96239 0.0001	0.96140 0.0001
CALCIUM	0.85017 0.0001	0.76115 0.0040	0.94050 0.0001	0.61293 0.0001	1.00000 0.0000	0.87205 0.0001	0.61345 0.0001	0.71690 0.0001
CHLORIDE	0.75167 0.0001	0.24215 0.4254	0.89049 0.0001	0.47530 0.0002	0.87205 0.0001	1.00000 0.0000	0.56357 0.0001	0.70010 0.0001
SODIUM	0.89227 0.0001	0.65831 0.0199	0.91728 0.0001	0.96239 0.0001	0.61345 0.0001	0.56357 0.0001	1.00000 0.0000	0.98529 0.0001
LCOND'	0.93988 0.0001	0.87433 0.0002	0.96137 0.0001	0.96140 0.0001	0.71690 0.0001	0.70010 0.0001	0.9852 0.0001	91.00000 0.0000

'Laboratory conductance.

Discriminant Analysis

A stepwise discriminant analysis was conducted on normalized values of each variable in the data set (Appendix A-4). After five steps in the analysis, four variables, natural log area, natural log maximum depth of the reservoir, natural log date of dam closure, and the natural log pH were selected (Table 4). The criterion used for selection of these variables was the significance level (α = 0.10) of an F-test from an analysis of covariance where the variables selected act as covariates and the variable under consideration is the dependent variable. We had a selection data set of 29 lakes that was subjected to a stepwise discriminant analysis being performed at two class levels (successful vs. unsuccessful) with 13 variables. The proportion of successful stockings in these 29 lakes was 51.7% and 48.3% for unsuccessful lakes.

The importance of the four significant variables in affecting walleye success is shown in Figures 2 and 3. The proportion of waters where walleye were successfully established was substantially higher at pH values in excess of 8.0 (Fig. 2). The optimum maximum depth to successfully establish walleye was in excess of 15.1 m (50 feet) (Fig. 2). With the exception of waters in the 75.7 m (250 feet) class, deeper waters consistently had higher success rates. Also, the proportion of successful plants of walleye increased

Table 4. Summary statistics of stepwise discriminant analysis on reservoirs.

STEP	VARIABLE ENTERED	NUMBER IN	PARTIAL R**2	F STATISTIC	PROB > F
1	LAREA	1	0.4350	20.791	0.0001
2	LMAXDEP	2	0.3784	15.828	0.0005
3	LPH	3	0.1093	3.067	0.0922
4	LDATE	4	0.2693	8.846	0.0066

LAREA = natural log of surface area in acres
LMAXDEP = natural log of maximum depth in feet
LPH = natural log of Ph
LDATE = natural log of the date of dam closure

Wilks' Lambda = 0.22855901 F(4,24) = 20.251 Prob > F =0.00001
Pillai's Trace = 0.771441 F(4,24) = 20.251 Prob > F =0.00001
Average Squared Canonical Correlation = 0.77144099

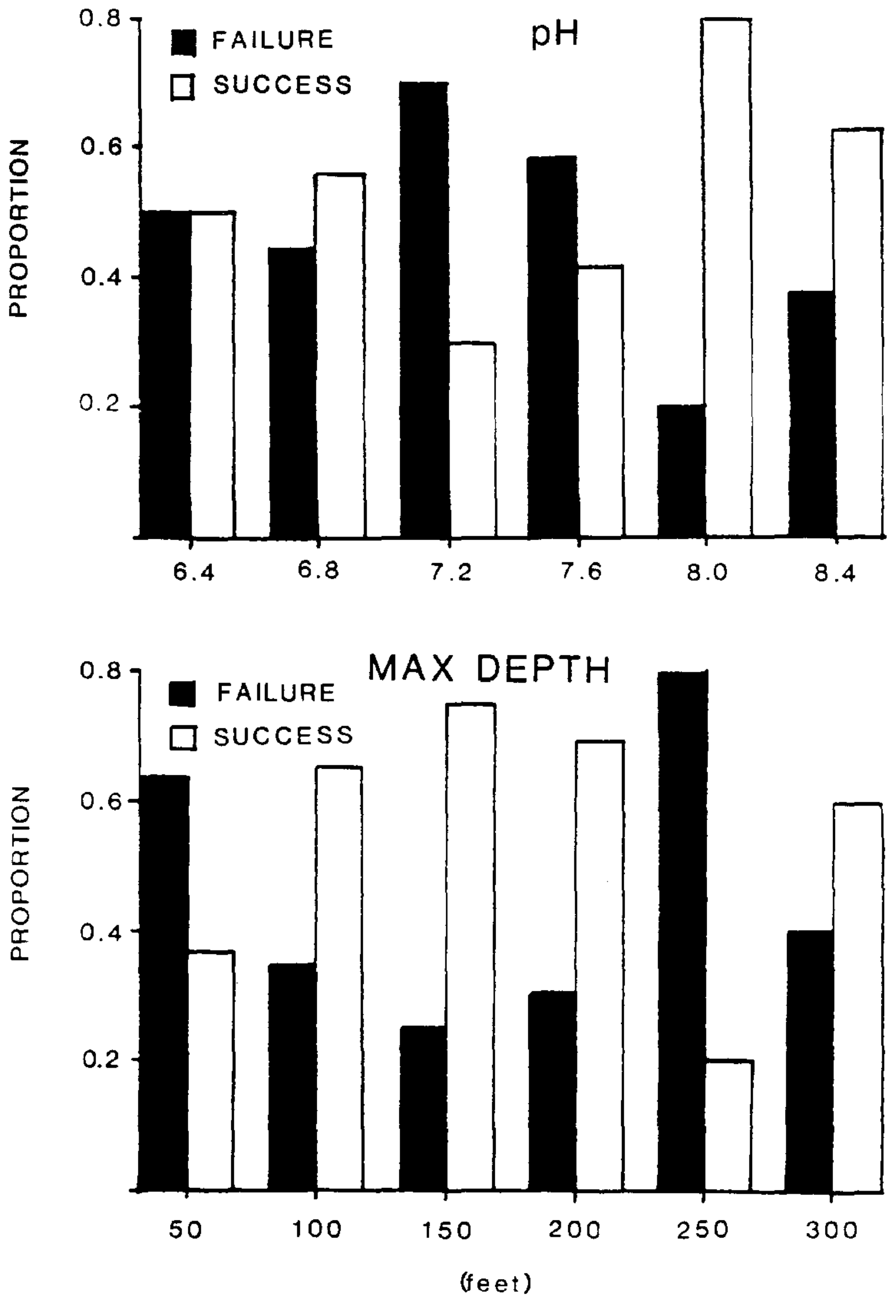

Figure 2. Proportion of waters surveyed where walleye were successfully or unsuccessfully established as a function of pH and maximum depth.

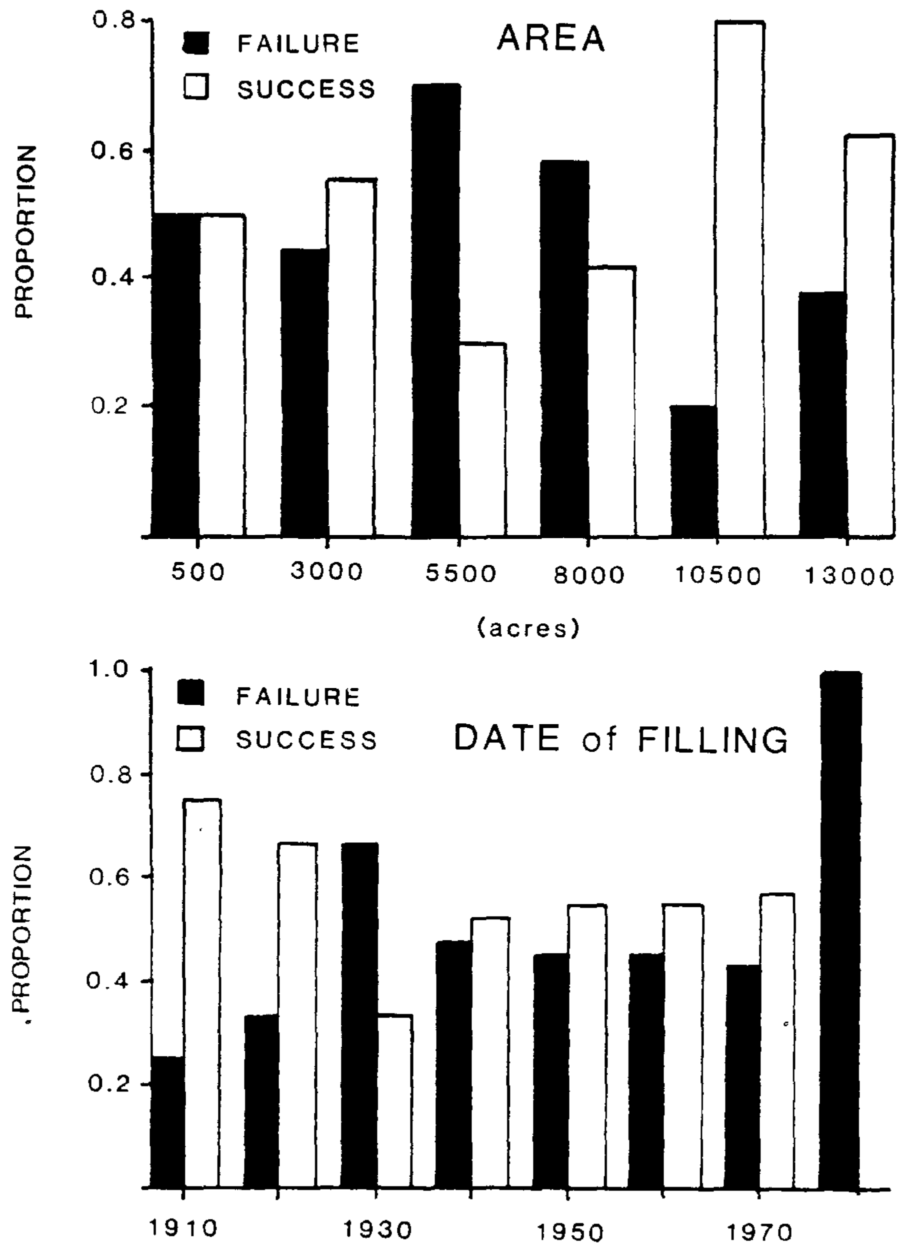

Figure 3. Proportion of waters surveyed where walleye were successfully or unsuccessfully established as a function of surface area and date of reservoir filling.

substantially in waters exceeding 3238 ha (8000 surface acres) (Fig. 3a). In contrast, waters smaller than 3238 ha averaged about 50% success. Date of filling had a less obvious effect on the success of establishing walleye (Fig. 3). Impoundments constructed before 1920 manifested the highest proportion of successful introductions of walleye.

Using the four significant variables, a second discriminant analysis was computed to calculate the value of the discriminant functions for classifying the observations into successful or unsuccessful waters. We assumed a prior probability level of 0.5 for each group although 44.2% of the 77 lakes in the analysis were classified as unsuccessful.

Results of the test of homogeneity of the within covariance showed no significance (χ^2 = 15.052; $P > 0.10$; 10 d.f.). Since the Chi-square value was not significant, a pooled covariance matrix was used in the calculation of the discriminant functions. The discriminant functions were:

unsuccessful=-391816.96721368-128.50555741(LAREA)+
177.44404855(LMAXDEP)+1530.80634059(LPH)+
103068.45371374(LDATE)

successful=-391734.75831752-127.80289371(LAREA)+
177.39175438(LMAXDEP)+1534.28847389(LPH)+
103055.92893865(LDATE)

where: LAREA = natural log of surface area (acres)

LMAXDEP = natural log of maximum depth (feet)

LPH = natural log of pH

LDATE = natural log of the date of dam closure

The highest value from these linear discriminant (Fisher's) functions (successful vs. unsuccessful) determines in what category the observation will be placed. The result of our analysis indicated that 74.6% of the lakes in our data set were classified correctly while 25.4% were misclassified (Appendix A-6).

Model Application

We applied our predictive model to six reservoirs scattered throughout Idaho. Our model predicted that walleye generally could be successfully established in these reservoirs, if stocking were deemed appropriate by the Department of Fish and Game (Table 5). American Falls Reservoir (Probability of success = 0.91), in eastern Idaho, and Cascade Reservoir (Probability of success = 0.84), in central Idaho, exhibited the highest possibilities for successfully establishing walleye.

Loop Analysis

We evaluated a number of possible situations in Idaho in which walleye could be introduced using loop analysis to assess possible adverse species interactions within the receiving ecosystem (Fig. 1).

Table 5. Data from selected reservoirs in the Columbia Basin and the probability of successfully establishing walleye based on output from a predictive model.

Reservoir	River System	Date of Closure	pH	Area (ha)	Depth (m)	Probability Success
American Falls	Snake	1927	8.05	22906	21	0.914
C.J. Strike	Snake	1952	8.4	2001	27	0.637
Brownlee	Snake	1958	8.5	6070	83	0.798
Cascade	Payette	1948	7.9	11453	20	0.843
Dworshak	Clearwater	1971	6.9	6916	191	0.651
Lower Granite	Snake	1975	7.9	3602	42	0.359
Lake Roosevelt	Columbia	1941	7.7	32781	119	0.910
John Day	Columbia	1967	7.9	21854	44	0.874
Salmon Falls	Snake	1910	8.8	1376	66	0.679

The first scenario we examined was walleye introduced into a system with a salmonid predator and a prey base common to both species (Fig. 1b). When walleyes consume the prey (e.g. kokanee - Oncorhynchus nerka) of the salmonids (e.g. chinook salmon - Oncorhynchus tshawytscha) and the salmonids, the result would be an unstable ecosystem. The equations at the F_1 and F_2 levels imply stability, while one term ($a_{12}a_{23}a_{31}$) is positive at the F_3 level which suggests conditional stability (ambiguity). For this system to be stable (since the $a_{12}a_{23}a_{31}$ term is positive at the F_3 level), walleye must obtain the bulk of their food from the salmonids, whereas the salmonids must be obtaining their food from the prey. Second, while most of the walleye population growth must be attributed to predation on salmonids, walleye also must have a negative influence on the prey base to create an overall negative feedback. If the above conditions are satisfied, the system with walleye, a prey species, and a salmonid predator could be locally stable, depending on the magnitude of the $a_{31}a_{12}a_{32}$ term since all the other terms cancel out in the F_3 level when evaluated using the Routh-Hurwitz criterion.

The second scenario examined walleye and salmonids competing for food as both species obtain their growth from the same prey base (Fig. 1c). For example, redside shiners (Richardsonius balteatus) might be the principal food item of walleye and a salmonid predator brown trout (Salmo trutta). Thus, two species competing for the same limited food source could create an unstable ecosystem. This system becomes conditionally unstable at the second level. The only possibility for stability to occur at this level (term $a_{32}a_{23}$ is positive) is if competition between walleye and salmonids were relatively minor.

The third scenario examined walleyes and salmonids feeding on the same prey base, but because of the abundance of prey, are not in competition (Fig. 1d). If walleyes do not feed on the salmonids then stability may result, providing the Routh-Hurwitz theorem also is satisfied.

The last scenario examined walleye being introduced into an ecosystem with two prey species. Results of loop analysis suggest stability, providing that walleye are the only top predator in the ecosystem (Fig. 1e).

DISCUSSION

Results of our survey indicated that 86% of the responding states and provinces have interest in obtaining a predictive methodology to assess the success of establishing walleye. Our survey indicated that, at present, fisheries management agencies have experienced an average success rate of 35% in establishing reproducing walleye populations. However, 44% of the lakes reported by the agencies contained successfully established walleye populations. Although a 35% success rate is lower than that (48%) reported by Laarman (1978), we believe that the 44% estimate is probably more representative of the actual success rate of introducing walleye throughout North America. Laarman (1978) based his estimate on 27 lakes as compared to 542 surveyed in this study. We excluded Canadian lakes and reservoirs from the analysis (Appendix A-2) because of the possible difficulty and time required to collect the water quality and morphometric data. The omission of Canadian Lakes, however, resulted in skewing the data set to a higher success rate (61%) than indicated by our survey and that reported by Laarman (1978).

Variables in stepwise discriminant analysis are entered one at a time; the first variable selected contributes most to the discriminatory power of the model as measured by Wilks' lambda, the likehood ratio criterion. The closer the statistic, Wilks' lambda, is to 0 the better the discriminatory power of the model. The Wilks' lambda value determined by our analysis was 0.2285 (Table 4). As variables are entered into the model, and fail to meet the selection criterion at a later step in the analysis, they are removed from the model. After all variables included in the data set either meet the criterion to stay or are eliminated the process stops. In our analysis of 13 variables, only the transformed variables of area, maximum depth, pH, and date of dam closure were selected by this process.

Another selection process using discriminant analysis is the value of the average squared canonical correlation. The canonical correlation helps identify the linear combinations of each set of variables which have the highest association with the dependent variable (Johnson and Wichern 1982). With an average squared canonical correlation of 1.0, the model yields perfect discrimination. Our analysis produced a canonical correlation of 0.77 which means that 77% of the time the classification of the lakes (successful vs. unsuccessful) would be accurately separated in all or most directions of discriminant space. However, we conducted another discriminant analysis using the four variables selected by the stepwise discriminant analysis on 77 reservoirs. The results of that analysis differed approximately 3% from that predicted by the average squared canonical correlation in the stepwise discriminant analysis (74% vs 77%). A few of the reservoirs misclassified in the discriminant analysis (Appendix A-6) are borderline as to which category they were best suited. We believe that a 3% difference in the predicted vs. actual in our sample data set adds credibility to our ability to discriminate between waters that could and those that could not support a walleye population.

The variables that we found to be significant in influencing walleye success are generally supported by the literature. For example, area, the first variable selected and the major contributor towards the separatory power of the model, is reported in the literature to affect walleye success. Colby et al. (1979) reported that walleye prefer bodies of water larger than 400 ha or 988.4 acres. The inclusion of area as a major factor is further supported by results of our t-test analysis which showed walleye were more commonly established in larger resevoirs (Table 2).

Walleyes are typically found in moderately shallow waters where shelter, turbidity, or color shields their eyes from light (Colby et al. 1979). Results of our analysis suggest that walleye may be more successful in lakes with deeper maximum depth (Fig. 2). In addition to occluding light, larger and deeper reservoirs will more likely thermally stratify. Colby et al. (1979) reported that walleye seem to prefer larger stratified bodies of water. Our selection of area (Fig. 3) and depth compare favorably with the results of a discriminant analysis by Johnson et al. (1977) who found that area and depth were the most important factors in assessing lake suitability for walleye and other fishes.

Although Scherer (1976) reported that walleye occur in waters having a pH of 6.0 to 9.0 with little change in abundance within that range, our results suggest the importance of pH in establishing a reproducing population (Fig. 2). From our analyses, walleye are more successful in reservoirs having a higher pH value (Table 2). The relationship between pH and walleye success is not clear. Possibly, higher pH values are associated with higher nutrient levels and higher nutrient levels are found in mesotrophic to eutrophic bodies of water (Cole 1979). If so, this agrees with Regier et al. (1969) who reported that walleyes attain maximum abundance in mesotrophic waters.

The final variable selected by the stepwise discriminant analysis was date of dam closure. Selection of this variable suggests that walleye are more successful in older reservoirs (Fig. 2). Older reservoirs collect more nutrients and, thus, become more eutrophic.

Our FORTRAN model (Appendix A-7) using the inverse of the covariance matrix and the discriminant coefficients from the discriminant analysis, provides a biologist with a computationally easy method of evaluating the probability of successfully establishing a reproducing walleye population. As written, this model lends itself to translation into other computer languages such as Basic, Pascal, or PL-1 which could increase its utility for field biologists. Applying the model to selected reservoirs in Idaho demonstrated that American Falls Reservoir, in eastern Idaho, has the highest probability of successful establishment of walleye of any tested (Table 5). In contrast, Lower Granite (Lake Byran) Reservoir, in eastern Washington, manifested the lowest probability for successful establishment of walleye (0.359). We must emphasize, however, that we are not endorsing the introduction of walleye into these systems. State fishery management agencies must make this decision following thorough biological, social, and economic evaluations (Bennett 1979). The purpose of these evaluations included in this report is to demonstrate the application of the model. Because of a limited data base we can not adequately validate the model. However, using a sample data set from Lake Roosevelt and John Day, both Washington reservoirs, and Salmon Falls Creek Reservoir, in southern Idaho, the model predicted that walleye could be successfully established in each. Lake Roosevelt (Nigro et al. 1983) and John Day (Hjort et al. 1981) which have established walleye populations manifested the highest probabilities of success while Salmon Falls Creek, also with an established walleye population (Bell 1982), had a lower probability of success (Table 5).

We believe this model will accurately assess the suitability of waters for establishing walleye. Limited data were a definite constraint. Although our survey included 542 reservoirs, the discriminant analysis only could be conducted on 77 lakes. As more data becomes available, further refinement of the model could increase its accuracy. Other variables that could increase the predictive capability of the model are: amount and type of spawning habitat (Johnson 1961; Machniak 1975), temperature during different seasons (Hokanson 1977); water level and velocity at time of spawning (Priegel 1970); amount of zooplankton for larval fish (Priegel 1970; Johnson 1969); the potential amount of standing crop of prey and predators; and, size and number of fish stocked. However, data on these parameters are not currently available in a sufficient number of reservoirs. Ideally, the model should have used the actual standing crop of walleyes in the body of water in lieu of their actual presence or absence. Use of standing crops of walleye could have provided a better indicator of successful establishment than success or failure. For example, limited reproduction may occur, but the body of water might not support a successful walleye fishery. A lack of data on standing crops, however, made this impossible.

Results of our study can be used by a manager without applying the model. Waters having the highest probability of establishing walleye have a pH in excess of 8.0, a maximum depth in excess of 15 m (50 feet), surface area larger than 3238 ha (8000 acres) and impounded before 1920 (Figs. 2 and 3). The relative importance of these four factors was found to be, in decending order, area, maximum depth, pH and date of impoundment (Table 4). We believe that area and depth are probably the two more important factors for a manager to consider when assessing the likelihood of establishing walleye in an uninhabited water. These two factors were deemed the most important in assessing habitat suitability for walleye by Johnson et al. (1977). Area, maximum depth and pH were the most important factors affecting walleye success in lakes throughout the U.S. (McArthur 1985).

With the use of loop analysis we are assuming that walleyes have been established in a reservoir by stocking and at the time of stocking the ecosystem is in a state of temporary equilibrium. With the four scenarios presented and analysed by loop analysis, two were qualitatively unstable while the others were qualitatively stable. In all cases where conditional stability resulted, a definite need exists for further quantitative analysis to determine the degree of stability in the system. However, we believe that the type of qualitative systems analysis used here can best be used to make first order approximations of the community system behavior. This type of analysis also helps the biologist identify data gaps. If the intensity of the interactions could be quantified and the system of differential equations developed for the individual elements of the community matrix, quantitative analysis could be made by substitution back into the loop expansion equations or by obtaining eiganvalues of the matrix. With a quantitative analysis, an eigenvector analysis may give the biologist an idea which components contribute strong oscillations since these are the variables which contribute to strong complex roots of the stability analysis. Even with a qualitative analysis the following generalizations can be made: (1) Predator-prey systems tend to stabilize the communities, if mortality of the prey is compensatory (e.g. Fig 1b), (2) competitive and symbiotic relationships tend to destabilize communities as in Figure 1c (May 1974; Levins 1975), (3) inherent stability in the system is independent of the species diversity, and (4) in the systems that are conditionally stable, the intensities of some species interaction are more important than those of others. System stability also is affected by the relative strengths of feedback at different hierarchical levels (Li and Moyle 1981). The principle of the Routh-Hurwitz theorem is that a system can be locally unstable if the system overreacts. Patterns of oscillatory behavior will be caused by time lags. This will happen if the negative feedback at the lower levels is less than the feedback at the higher levels (Levins 1975).

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APPENDIX A-1. Questionnaire survey sent to state and provincial fisheries management personnel.

July 22, 1983

Aqency Address

Dear :

We are currently attempting to construct a methodology to predict whether an introductory stocking of walleye will be successful. To do this we are attempting to identify those factors which affect the success or failure of walleye in various lakes and reservoirs. Our analysis will require a great deal of data, and your assistance is vital to the success of our effort. Please answer the following questionnaire and note the potential to benefit from this survey (question #5).

(1) Has your state introduced walleye into bodies of water where this species was not previously reported?
yes______________ no________________
(2) Did this introductory stocking or subsequent stocking result in a reproducing population?
yes______________ no________________
(3) What was the approximate percent success rate? __________
(4) Please send a list of lakes and reservoirs stocked with walleye, and indicate which ones have a self-sustaining population as a result of stocking. Please note that those unsuccessful are as important as those deemed successful.
(5) Would you like a copy of the results?
yes______________ no_________________

Thank you very much for your assistance. A self-addressed, stamped envelope is enclosed for your convenience.

Sincerely,

David H. Bennett
Assoc. Professor of
Fishery Resources

APPENDIX A-2. Lakes and reservoirs in which walleye were successfully or unsuccessfully established. Those marked as uncertain indicate a lack of data to make this assessment.

STATE	NAME	CLASSIFICATION
ARIZONA	APACHE LAKE	UNSUCCESSFUL
	CANYON LAKE	UNSUCCESSFUL
	FOOL HOLLOW LAKE	SUCCESSFUL
	LAKE MARY	UNSUCCESSFUL
	LAKE PLEASANT	UNSUCCESSFUL
	LONG LAKE	UNSUCCESSFUL
	LYMAN LAKE	UNSUCCESSFUL
	SAGUARO LAKE	UNSUCCESSFUL
ARKANSAS	GREERS FERRY	SUCCESSFUL
	NORFORK	SUCCESSFUL
	BULL SHOALS	SUCCESSFUL
	OUACHITA	SUCCESSFUL
	HAMILTON	UNCERTAIN
	CATHERINE	UNCERTAIN
	NIMROD	UNSUCCESSFUL
	BLUE MOUNTIAN	UNSUCCESSFUL
	GILTHAM	UNSUCCESSFUL
	BEAVER	UNSUCCESSFUL
	DE GRAY	UNSUCCESSFUL
	HINKLE	UNSUCCESSFUL
CALIFORNIA	EL CAJITAN	UNSUCCESSFUL
	SAN VINCENTE	UNSUCCESSFUL
	PUDDINGSTONE	UNSUCCESSFUL
	CASITAS	UNSUCCESSFUL
	CACHUMA	UNSUCCESSFUL
COLORADO	ADOBE CREEK RESERVOIR	UNCERTAIN
	HENRY RESERVOIR	UNCERTAIN
	QUEENS RESERVOIR	UNCERTAIN
	NEE NOSHE RESERVOIR	UNCERTAIN
	JOHN MARTIN RESERVOIR	UNCERTAIN
	LONE HAGLER RESERVOIR	UNCERTAIN
	LOVELAND RESERVOIR	UNCERTAIN
	CHERRY CREEK RESERVOIR	UNCERTAIN
	BOYD LAKE	UNCERTAIN
	HORSESHOE RESERVOIR	UNCERTAIN
	BOEDECKER RESERVOIR	UNCERTAIN
	BOULDER RESERVOIR	UNCERTAIN
	LONETREE RESERVOIR	UNCERTAIN
CONNECTICUT	CANDLEWOOD LAKE	UNSUCCESSFUL
	LAKE LILLINONAH	UNSUCCESSFUL
FLORIDA	JULIANA	UNSUCCESSFUL
	SCOTT	UNSUCCESSFUL
	GIBSON	UNSUCCESSFUL
	SENECA	UNSUCCESSFUL

STATE	NAME	CLASSIFICATION
FLORIDA (Cont.)	MOON	UNSUCCESSFUL
	ECHO	UNSUCCESSFUL
	MIRROR	UNSUCCESSFUL
	TENNESSEE	UNSUCCESSFUL
	JUNIPER	UNSUCCESSFUL
	ORANGE	UNSUCCESSFUL
	KOON	UNSUCCESSFUL
	SWIM	UNSUCCESSFUL
	OKEEHEELEE	UNSUCCESSFUL
	EMERALD	UNSUCCESSFUL
GEORGIA	LAKE SINCLAIR	UNSUCCESSFUL
	LANIER	SUCCESSFUL
	ALLATOONA	SUCCESSFUL
	BLUERIDGE	SUCCESSFUL
	BURTON	SUCCESSFUL
	NOTTELY	UNCERTAIN
	CHATUGE	SUCCESSFUL
	HARTWELL	SUCCESSFUL
IDAHO	SALMON FALLS RES.	SUCCESSFUL
	ONIEDA LAKE	SUCCESSFUL
INDIANA	HARDEN RESERVOIR	UNSUCCESSFUL
	BROOKVILLE RESERVOIR	UNSUCCESSFUL
	CLEAR LAKE	UNSUCCESSFUL
	LAKE FREEMAN	UNSUCCESSFUL
	LAKE JAMES	UNSUCCESSFUL
IOWA	RATHBUN RESERVOIR	SUCCESSFUL
	REDROCK RESERVOIR	SUCCESSFUL
	SAYLORVILLE RESERVOIR	SUCCESSFUL
	CORALVILLE RESERVOIR	SUCCESSFUL
	LAKE MACBRIDE	SUCCESSFUL
	LAKE ICARIA	SUCCESSFUL
	RED CREEK LAKE	SUCCESSFUL
	BIG CREEK LAKE	SUCCESSFUL
KANSAS	BIG HILL RES.	UNCERTAIN
	CEDAR BLUFF RES.	SUCCESSFUL
	CHENEY RES.	SUCCESSFUL
	CLINTON RES	UNSUCCESSFUL
	COUNCIL GROVE RES.	SUCCESSFUL
	EL DORADO RES.	UNCERTAIN
	ELK CITY RES	UNSUCCESSFUL
	FALL RIVER RES.	UNSUCCESSFUL
	GLEN ELDER RES.	SUCCESSFUL
	HILLSDALE	UNCERTAIN
	JOHN REDMOND RES.	UNSUCCESSFUL
	KANOPOPIS RES.	SUCCESSFUL
	KIRWIN RES.	SUCCESSFUL
	LA CYGNE RES.	UNSUCCESSFUL
	LOVEWELL RES	UNSUCCESSFUL
	MARION RES.	SUCCESSFUL

STATE	NAME	CLASSIFICATION
KANSAS (Cont.)	MELVERN RES	SUCCESSFUL
	MILFORD RES.	SUCCESSFUL
	NORTON RES.	UNSUCCESSFUL
	PERRY RES.	UNSUCCESSFUL
	POMONA RES.	UNSUCCESSFUL
	TORONTO RES.	UNSUCCESSFUL
	TUTTLE CREEK RES.	UNSUCCESSFUL
	WEBSTER RES.	SUCCESSFUL
	WILSON RES.	SUCCESSFUL
	WOLF CREEK RES.	UNCERTAIN
KENTUCKY	LAURAL RIVER LAKE	UNSUCCESSFUL
	CUMBERLAND LAKE	SUCCESSFUL
	NOLIN RIVER LAKE	UNSUCCESSFUL
	ROUGH RIVER LAKE	UNSUCCESSFUL
	MARTINS FORK LAKE	UNSUCCESSFUL
MARYLAND	DEEP CREEK LAKE	UNSUCCESSFUL
	ROCKY GAP LAKE	UNSUCCESSFUL
	LIBERTY RES.	UNSUCCESSFUL
	ROCKY GOURGE RES.	UNSUCCESSFUL
	TRIADELPHIA RES.	UNSUCCESSFUL
	LOCH RAVEN RES.	UNSUCCESSFUL
	CONOWINGO RES.	UNSUCCESSFUL
MASSACHUSETTS	QUABBIN RES.	UNSUCCESSFUL
	UPPER MYSTIC LAKE	UNSUCCESSFUL
	LAKE CHAUNCY	UNSUCCESSFUL
MISSISSIPPI	ENID RES.	UNSUCCESSFUL
MISSOURI	CLEARWATER LAKE	UNSUCCESSFUL
	SMITHVILLE LAKE	UNCERTAIN
	TRUMAN LAKE	UNCERTAIN
	LAKE PAHO	UNSUCCESSFUL
	SEVER LAKE	UNSUCCESSFUL
	HUMMEWELL LAKE	UNSUCCESSFUL
	FORREST LAKE	UNSUCCESSFUL
MONTANA	PABLO RES.	UNSUCCESSFUL
	RAINBOW LAKE	UNSUCCESSFUL
	BROWNES LAKE	UNSUCCESSFUL
	DAILEY LAKE	UNSUCCESSFUL
	CANAL LAKE	UNSUCCESSFUL
	COCHRAN RES.	UNSUCCESSFUL
	FARMERS RES.	UNSUCCESSFUL
	FREEZEOUT LAKE	UNSUCCESSFUL
	KOLAR RES. #1	UNSUCCESSFUL
	LAKE ELWELL	SUCCESSFUL
	LAKE FRANCES	SUCCESSFUL
	LAKE HELENA	SUCCESSFUL
	PISHKUN RES.	UNSUCCESSFUL
	RAINBOW DAM	UNSUCCESSFUL
	SHALE CREEK RES.	UNSUCCESSFUL
	TETON COUNTY	UNSUCCESSFUL
	WILLOW CREEK RES.	UNSUCCESSFUL

STATE	NAME	CLASSIFICATION
MONTANA (Cont.)	YELLOW WATER LAKE	UNSUCCESSFUL
	BIG HORN LAKE	UNSUCCESSFUL
	KLAS DAM ED	UNSUCCESSFUL
	BAINVILLE RES.	UNSUCCESSFUL
	COLE POND SW.	UNSUCCESSFUL
	CAVIS POND	UNSUCCESSFUL
	DREDGE CUT TROUT POND	UNSUCCESSFUL
	ESTER LAKE	UNCERTAIN
	FLAT LAKE	UNSUCCESSFUL
	FORT PECK REARING PONDS	UNCERTAIN
	FORT PECK RES.	SUCCESSFUL
	FRESNO RES.	SUCCESSFUL
	HANSON RES.	UNSUCCESSFUL
	HEDSTORM RES. #1	UNSUCCESSFUL
	HEDSTORM RES #2	UNSUCCESSFUL
	HERBERT-DRABBLES POND	UNSUCCESSFUL
	KWASNEY RES.	UNSUCCESSFUL
	LAKE 12	UNSUCCESSFUL
	LYONS RES.	UNSUCCESSFUL
	MCCHESNEY RES.	UNSUCCESSFUL
	MCNEIL PONDS	UNSUCCESSFUL
	MEDICINE LAKE	UNSUCCESSFUL
	NELSON RES.	SUCCESSFUL
	PAWLOWSKI RES.	UNSUCCESSFUL
	RAYMOND DAM	UNSUCCESSFUL
	SOUTH FORK RES.	UNSUCCESSFUL
	STRIKE RES.	UNSUCCESSFUL
	THORNLEY DEAD RIVER	UNSUCCESSFUL
	TILLISON DAM	UNSUCCESSFUL
	VALLEY COUNTY	UNSUCCESSFUL
	WHITESIDE RES.	SUCCESSFUL
	FRENCHMAN RES.	SUCCESSFUL
	BAKER LAKE	UNSUCCESSFUL
	BIRCHER RES.	UNSUCCESSFUL
	BRANES RES.	UNSUCCESSFUL
	BROWN POND #1	UNSUCCESSFUL
	BUSCH POND	UNSUCCESSFUL
	CARTER COUNTY	UNSUCCESSFUL
	CASTLE ROCK LAKE	SUCCESSFUL
	CHILDERS POND	SUCCESSFUL
	CLEARWATER RES.	UNSUCCESSFUL
	COCHRAN POND #1	UNSUCCESSFUL
	COLWELL RES.	UNSUCCESSFUL
	CUSTER COUNTY	UNSUCCESSFUL
	EDWARDS POND #2	UNSUCCESSFUL
	ENGDAHL RES.	SUCCESSFUL
	GARFIELD COUNTY	UNSUCCESSFUL
	GUESANBURN RES.	UNSUCCESSFUL
	GARTSIDE LAKE	UNSUCCESSFUL

STATE	NAME	CLASSIFICATION
MONTANA (Cont.)	HAISLETT DAM	UNSUCCESSFUL
	HORSE CREEK DAM	UNSUCCESSFUL
	HORTON POND	UNSUCCESSFUL
	KAUFMAN RES.	UNSUCCESSFUL
	JOHNSON DAM	UNSUCCESSFUL
	KELLY RES.	UNSUCCESSFUL
	KIBLER POND	UNSUCCESSFUL
	KUBESK RES.	UNSUCCESSFUL
	LAME STEER RES.	SUCCESSFUL
	NEEDLE BUTTE DAM	SUCCESSFUL
	PLUHAR RES.	UNSUCCESSFUL
	POWDER RIVER COUNTY	UNSUCCESSFUL
	PRAIRIE RIVER COUNTY	UNSUCCESSFUL
	REIGLER BROTHERS RES.	UNSUCCESSFUL
	ROSEBUD COUNTY	UNSUCCESSFUL
	RUSTAD RES.	UNSUCCESSFUL
	SCANLAN LAKE	UNSUCCESSFUL
	SHAFFER POND	UNSUCCESSFUL
	SHAFFER RES.	UNSUCCESSFUL
	SOUTH SANDSTONE RES.	SUCCESSFUL
	SPOTTED EAGLE RES.	UNSUCCESSFUL
	SQUIRES RES.	UNSUCCESSFUL
	TONGUE RIVER RES.	SUCCESSFUL
	U. S. RANGE STATION POND	UNSUCCESSFUL
	UPPER LOBELLA RES.	UNSUCCESSFUL
	VAUGHN POND	UNSUCCESSFUL
	VOEGLE RES.	UNSUCCESSFUL
	WESTROPE POND	UNSUCCESSFUL
	ZEMPLE RES.	UNSUCCESSFUL
NEBRASKA	LAKE MINATARE	SUCCESSFUL
	BOX BUTTE RESERVOIR	SUCCESSFUL
	WHITNEY LAKE	SUCCESSFUL
	LAKE MCCONAUGHY	SUCCESSFUL
	SUTHERLAND	SUCCESSFUL
	MALONEY	SUCCESSFUL
	JEFFERY	SUCCESSFUL
	JOHNSON	SUCCESSFUL
	ENDERS	SUCCESSFUL
	SWANSON	SUCCESSFUL
	RED WILLOW	SUCCESSFUL
	MEDICINE CREEK	SUCCESSFUL
	HARLAN	SUCCESSFUL
	SHERMAN	SUCCESSFUL
	MERRITT	UNSUCCESSFUL
	BRANCHED OAK	SUCCESSFUL
	PAWNEE	SUCCESSFUL
	WAGON TRAIN	SUCCESSFUL

STATE	NAME	CLASSIFICATION
NEVADA	RYE PATCH RES	SUCCESSFUL
	LAHONTEN RES.	SUCCESSFUL
	CHIMNEY CREEK RES.	SUCCESSFUL
NEW HAMPSHIRE	FRANKLIN PIERCE RES.	UNSUCCESSFUL
	MOORE RES	UNSUCCESSFUL
NEW JERSEY	LAKE HOPATCONG	UNSUCCESSFUL
NEW MEXICO	ELEPHANT BUTTE RES.	UNSUCCESSFUL
	CABALLO RES.	UNSUCCESSFUL
	COCLIT	SUCCESSFUL
	CONCHAS	SUCCESSFUL
	UTE	SUCCESSFUL
	LAKE SUMNER	SUCCESSFUL
	MCMILLIAN RES.	SUCCESSFUL
	CLAYTON LAKE	SUCCESSFUL
OHIO	HOOVER RES.	SUCCESSFUL
	BERLIN RES.	SUCCESSFUL
OKLAHOMA	CANTON	SUCCESSFUL
	FOSS	SUCCESSFUL
	ALTUS-LUGERT	SUCCESSFUL
	CHICKASHA	SUCCESSFUL
	TOM STEED	UNSUCCESSFUL
	KERR	UNSUCCESSFUL
	WEBBERS FALLS	UNSUCCESSFUL
	GRAND	UNSUCCESSFUL
	TENKILLER	UNSUCCESSFUL
	TEXOMA	UNSUCCESSFUL
	THUNDERBIRD	UNSUCCESSFUL
	ELLSWORTH	UNSUCCESSFUL
	LAWTONKA	UNSUCCESSFUL
	ARBUCKLE	UNSUCCESSFUL
	MURRAY	UNSUCCESSFUL
	FORT SUPPLY	UNSUCCESSFUL
	SALT PLAINS	UNSUCCESSFUL
RHODE ISLAND	WATCHANG POND	UNSUCCESSFUL
SOUTH CAROLINA	LAKE HARTWELL	SUCCESSFUL
	CLARKS HILL RES.	SUCCESSFUL
	LAKE MURRY	SUCCESSFUL
SOUTH DAKOTA	AUGOSTURA	SUCCESSFUL
	BELLE FOURCHE	SUCCESSFUL
	SHADEHILL	SUCCESSFUL
UTAH	CUTLER RES.	SUCCESSFUL
	UTAH LAKE	SUCCESSFUL
	DEER CREEK RES.	SUCCESSFUL
	GENNISON BEND RES.	SUCCESSFUL
	LAKE POWELL	SUCCESSFUL
	STARVATION RES.	SUCCESSFUL
	WILLARD BAY RES.	SUCCESSFUL
	DMAD RES.	SUCCESSFUL
	SEVIER BRIDGE RES.	SUCCESSFUL

STATE	NAME	CLASSIFICATION
VIRGINIA	LAKE ANNA	UNCERTAIN
	LAKE WHITEHURST	UNCERTAIN
	LAKE SMITH	UNCERTAIN
	LAKE TRASHMORE	UNCERTAIN
	WESTERN BRANCH RES.	UNCERTAIN
	LONE STAR LAKE	UNSUCCESSFUL
	LAKE BURNT MILL'S	UNCERTAIN
	LAKE ABEL	UNCERTAIN
	LAKE MANASSAS	UNCERTAIN
	LAKE ORANGE	UNCERTAIN
	LAKE BURKE	UNCERTAIN
	LAKE BRITTLE	UNCERTAIN
	BEAVER CREEK LAKE	UNSUCCESSFUL
	TOTIER CREEK LAKE	UNSUCCESSFUL
	FLUVANNA RUTITAN LAKE	UNSUCCESSFUL
	LAKE SHENANDOAH	UNSUCCESSFUL
	LAKE ABLEMARLE	UNSUCCESSFUL
	SMITH MOUNTIAN LAKE	SUCCESSFUL
	CLAYTOR LAKE	SUCCESSFUL
	CARVINS COVE	UNSUCCESSFUL
	AMELIA LAKE	UNSUCCESSFUL
	LEESVILLE RES.	SUCCESSFUL
	LAKE ROBERTSON	SUCCESSFUL
	HUNGRY MOTHER LAKE	UNCERTAIN
WASHINGTON	BILLY CLAPP LAKE	UNCERTAIN
	LAKE ROOSEVELT	SUCCESSFUL
	UPPER GOOSE RES.	UNCERTAIN
	PARA POND	UNCERTAIN
	I 82 POND #5	UNCERTAIN
WEST VIRGINIA	BEECH FORK LAKE	UNCERTAIN
	BLOOMINGTON LAKE	UNCERTAIN
	BLUESTONE LAKE	UNSUCCESSFUL
	BURNSTONE LAKE	UNCERTAIN
	EAST LYNN LAKE	UNSUCCESSFUL
	MOUNT STORM LAKE	UNCERTAIN
	R. D. BAILEY LAKE	UNCERTAIN
	STONECOAL LAKE	SUCCESSFUL
	SUMMERSVILLE LAKE	SUCCESSFUL
	SUTTON LAKE	SUCCESSFUL
	TYGART LAKE	SUCCESSFUL
WISCONSIN	ESCANABA LAKE	SUCCESSFUL
	DIAMOND LAKE	SUCCESSFUL
	WHEELER LAKE	SUCCESSFUL

STATE	NAME	CLASSIFICATION
WYOMING	GLENDO RES	SUCCESSFUL
	SEMINOLE RES.	SUCCESSFUL
	PATHFINDER RES.	SUCCESSFUL
	KEYHOLE RES.	SUCCESSFUL
	OCEAN LAKE	SUCCESSFUL
	BIGHORN LAKE	SUCCESSFUL
	LAKE ABSARRACA	SUCCESSFUL
	BOYSEN LAKE	SUCCESSFUL

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APPENDIX A-4. Transformations used to normalize variables for discriminant analysis.

LAREA= NATURAL LOG(AREA)

LMAXDEP=NATURAL LOG(MAXDEP)

LELEV=NATURAL LOG(ELEV)

LDATE=NATURAL LOG(DATEFILL)

LPH=NATURAL LOG(PH)

LALKAL=SQRT(ALKAL)

LPHOSP=NATURAL LOG(PHOSP)

LTOTN=NATURAL LOG(TOTALN)

LHARD=SQRT(HARDNESS)

LTURB=SQRT(TURBITY)

LCHLORA=NATURAL LOG(CHLOROA)

LTDS=SQRT(TDS)

LCONDUCT=SQRT(CONDUCT)

LCOLOR=NATURAL LOG(COLOR)

LSULF=NATURAL LOG(SULFATES)

LCALCIUM=NATURAL LOG(CALCIUM)

LCLORIDE=NATURAL LOG(CLORIDE)

LSODIUM=NATURAL LOG(SODIUM)

LPOTASS=NATURAL LOG(POTASS)

LSECCHI=NATURAL LOG(SECCHI)

LCONDL=NATURAL LOG(CONDL)

APPENDIX A-5. Equations resulting from Type II regression analysis.

CONDUCTANCE=167.49073630+1.23583385(TOTAL DISSOLVED SOLIDS)

TOTAL DISSOLVED SOLIDS=-21.18397199+0.66417196CONDUCTANCE

TDS=200.06867999+0.40581551(LABORATORY CONDUCTANCE)

LABORATORY CONDUCTANCE=-377.26140050+2.24163120(TDS)

CHLORIDE=-14.91672111+0.13024296CONDUCTANCE

CONDUCTANCE=253.39203460+5.47316815CHLORIDE

CONDUCTANCE=79.25666585+10.71589685CALCIUM

CALCIUM=4.86736071+0.0733963CONDUCTANCE

CHLORIDE=-10.13943113+1.08305407CALCIUM

CALCIUM=30.62479056+0.49487737CHLORIDE

CONDUCTANCE=0.21450626+0.90265589(LABORATORY CONDUCTANCE)

LABORATORY CONDUCTANCE=1.4696618+1.10475711CONDUCTANCE

CONDUCTANCE=-8.07708542+2.82525863HARDNESS

HARDNESS=18.75383627+0.32681728CONDUCTANCE

HARDNESS=114.9038474+1.33314954SODIUM

SODIUM=-210.9414893+1.22602613HARDNESS

SODIUM=-11.61570194+0.14038483CONDUCTANCE

CONDUCTANCE=184.8493857+5.86474872SODIUM

LABORATORY CONDUCTANCE=142.6518807+2.82968386SULFATES

SULFATES=-32.75052982+0.33289417(LABORATORY CONDUCTANCE)

SULFATES=-300.6757713+2.1285969SODIUM

SODIUM=7.41371515+0.39395621SULFATES

SODIUM=-25.01447832+0.14993164(LABORATORY CONDUCTANCE)

LABORATORY CONDUCTANCE=186.3034572+6.51456355SODIUM

LABORATORY CONDUCTANCE=511.7586640+0.78369733HARDNESS

HARDNESS=38.55907685+0.26721495(LABORATORY CONDUCTANCE)

APPENDIX A-6. Listing of reservoirs misclassified by the discriminant analysis.

Reservoir Name	State	CLASSIFIED INTO	Probability
De Gray	AR	Successful	0.7300
Candlewood	CT	Successful	0.5970
Sinclair	GA	Successful	0.6802
Blueridge	GA	Unsuccessful	0.6425
Burton	GA	Unsuccessful	0.6453
Lake McBride	IA	Unseccessful	0.6548
Cedar Bluff	KA	Unsuccessful	0.7584
Clinton	KA	Successful	0.5851
Council Grove	KA	Unsuccessful	0.5100
J. Redmond	KA	Successful	0.6908
Kerwin	KA	Unsuccessful	0.5764
Perry	KA	Successful	0.6902
Quabbin	MA	Successful	0.6568
Lake Helena	MT	Unsuccessful	0.5463
Bighorn Lake	MT	Successful	0.7491
Enid	MS	successful	0.6214
Hoover	OH	Unsuccessful	0.6425
Berlin	OH	Unsuccessful	0.6629
Elephant Butte	NM	Successful	0.8811
Summersville	WV	Unsuccessful	0.7344
Sutton Lake	WV	Unsuccessful	0.8062

APPENDIX A-7. Listing of FORTRAN program for evaluating the probability of successfully establishing a self-sustaining walleye population.

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C *****************************************************************************
C                         WALLEYE INTRODUCTION PROGRAM
C
C WRITTEN BY:     THOMAS J. MCARTHUR
C DATE LAST MODIFIED:  JUNE 22, 1984
C
C PURPOSE OF PROGRAM:  TO PREDICT WHETHER THE OUTCOME OF A WALLEYE
C                      INTRODUCTION WILL BE THE ESTABLISHMENT OF
C                      SELF-SUSTAINING POPULATION IN A RESERVIOR. INPUT
C                      FOR THE PROGRAM IS SURFACE AREA, MAXIMUM DEPTH,
C                      PH, AND THE DATE OF DAM CLOSURE.  THE RESULTS
C                      ARE BASED ON A DISCRIMINANT ANALYSIS.
C
C
C
C COPYRIGHT 1984 IDAHO WATER RESOURCE INSTITUTE
C *****************************************************************************
      DIMENSION COVINV(4,4)
C******************************************************************************
C     INPUT OF THE INVERSE OF THE POOLED COVARIANCE MATRIX
C******************************************************************************
      DATA COVINV(1,1),COVINV(1,2),COVINV(1,3),COVINV(1,4),
     *COVINV(2,1),COVINV(2,2),COVINV(2,3),COVINV(2,4),
     *COVINV(3,1),COVINV(3,2),COVINV(3,3),COVINV(3,4),
     *COVINV(4,1),COVINV(4,2),COVINV(4,3),COVINV(4,4)/0.7379162958961,
     *-0.693461592855,-1.19968309588,-17.0001494554,-0.693461592855,
     *2.539000714287,1.701498028541,22.23702422925,-1.19968309588,
     *1.701498028541,127.3082962818,168.5738833014,-17.0001494554,
     *22.23702422925,168.5738833014,13565.66144821/
C******************************************************************************
C    INSTRUCTIONS TO THE USER ON THE INPUT AND RANGE OF VALUES FOR
C    TO VARIABLES (AREA, MAXIMUM DEPTH, PH, AND DATE OF DAM CLOSURE
C******************************************************************************
      WRITE(6,401)
401   FORMAT('1')
      WRITE(6,20)
20    FORMAT(2X,'THIS PROGRAM IS DESIGNED TO HELP PREDICT WHERE WALLEYE'
     *,/2X,'ESTABLISH A SUCCESSFUL REPRODUCING POPULATIONS IF INTRODUCED
     *',/2X,'INTO RESERVOIRS WHERE THEY ARE NON-NATIVE.  THE INPUT REQUI
     *RED',/2X,'FOR THE PROGRAM IS AREA (ACRES OR HECTARES), MAXIMUM DEP
     *TH (FEET',/2X,'OR METERS), PH, AND THE DATE OF RESERVOIR CLOSURE.'
     *,//2X,'RANGE OF VALID VALUES FOR AREA: 105.8 ACRES (42.8 HECTARES)
     * TO 55951',/2X,'ACRES (22263 HECTARES)'//2X,'RANGE OF VALID VALUES
     * FOR MAXIMUM DEPTH: 6 FEET (1.9 METERS) TO 495 FEET',/2X,'(150.9 M
     *ETERS)'//2X,'RANGE OF VALID VALUES FOR PH: 6.17 TO 8.7'//2X,'THE R
     *ANGE OF VALID VALUES FOR DAM CLOSURE: 1908 TO 1979')
C******************************************************************************
```

```
C     DECISION POINT OF WHETHER THE PROGRAM INPUT IS TO BE METRIC OR
C     ENGLISH
C*****************************************************************************
 8    WRITE(6,21)
21    FORMAT(2X,'IF THE INPUT DATA IS METRIC ENTER 1; ELSE ENTER 2')
      READ(5,*)QUEST
      IF(QUEST.EQ.1)GOTO 28
C*****************************************************************************
C     INPUT SECTION OF THE PROGRAM IF THE VARIABLES, AREA AND
C     MAXIMUM DEPTH ARE IN ACRES AND FEET.
C*****************************************************************************
      WRITE(6,1)
  1   FORMAT(2X,'ENTER THE AREA OF THE BODY OF WATER TO BE CONSIDEDED IN
     * ACRES')
      READ(5,*)AREA
      WRITE(6,2)
  2   FORMAT(2X,'ENTER THE MAXIMUM DEPTH IN FEET OF THE RESERVOIR')
      READ(5,*)DEPTH
      GOTO 29
C*****************************************************************************
C     INPUT SECTION OF THE PROGRAM IF THE VARIABLES, AREA AND
C     MAXIMUM DEPTH ARE IN HECTARES AND METERS.  THE VARIABLES ARE
C     COVERTED TO ACRES AND FEET.
C*****************************************************************************
 28   WRITE(6,31)
 31   FORMAT(2X,'ENTER THE AREA OF THE BODY OF WATER TO BE CONSIDEDED IN
     * HECTARES')
      READ(5,*)AREA
      AREA=AREA/2.471
      WRITE(6,32)
 32   FORMAT(2X,'ENTER THE MAXIMUM DEPTH IN FEET OF THE RESERVOIR')
      READ(5,*)DEPTH
      DEPTH=3.280839895
C*****************************************************************************
C     INPUT SECTION FOR THE OTHER TWO VARIABLES, PH AND DATE OF DAM
C     CLOSURE.  THE NATURAL LOGS ARE ALSO OF ALL VARIABLES.
C*****************************************************************************
 29   WRITE(6,33)
 33   FORMAT(2X,'ENTER THE MEAN PH OF THE RESERVOIR')
      READ(5,*)PH
      WRITE(6,34)
 34   FORMAT(2X,'ENTER THE DATE OF CLOSURE OF THE DAM')
      READ(5,*)DATE
      X1=ALOG(AREA)
      X2=ALOG(DEPTH)
      X3=ALOG(PH)
      X4=ALOG(DATE)
C*****************************************************************************
C    CALCULATION OF THE VALUES FOR THE TWO DISCRIMANT FUNCTIONS (D1,D2)
C*****************************************************************************
      D1=-391816.96721368+(-128.50555741*X1+177.44404855*X2+1530.8063405
     *9*X3+103068.45371374*X4)
      D2=-391734.75831752+(-127.80289371*X1+177.39175438*X2+1534.2884738
```

```
     *9*X3+103055.92893865*X4)
C***********************************************************************
C   CALCULATION OF THE TERM USED IN THE PROBALILITY FUNCTION USING:
C   (TRANSPOSE OF INPUT VECTOR)X(INVERSE OF THE COVARIANCE MATRIX)X
C   (INPUT VECTOR)
C***********************************************************************
      TX1=X1*COVINV(1,1)+X2*COVINV(2,1)+X3*COVINV(3,1)+X4*COVINV(4,1)
      TX2=X1*COVINV(1,2)+X2*COVINV(2,2)+X3*COVINV(3,2)+X4*COVINV(4,2)
      TX3=X1*COVINV(1,3)+X2*COVINV(2,3)+X3*COVINV(3,3)+X4*COVINV(4,3)
      TX4=X1*COVINV(1,4)+X2*COVINV(2,4)+X3*COVINV(3,4)+X4*COVINV(4,4)
      TERM=(TX1*X1+TX2*X2+TX3*X3+TX4*X4)*(-0.5)
C***********************************************************************
C    CALCULATION OF THE PROBILITY VALUES FOR A SUCCESSFUL INTRODUCTION
C    OR AN UNSUCCESSFULL INTRODUCTION
C***********************************************************************
      SCORE1=D1+TERM
      SCORE2=D2+TERM
      PROB1=EXP(SCORE1)/(EXP(SCORE1)+EXP(SCORE2))
      PROB2=EXP(SCORE2)/(EXP(SCORE1)+EXP(SCORE2))
C***********************************************************************
C     OUTPUT SECTION OF THE PROGRAM
C***********************************************************************
      IF(PROB2.GE.0.5)WRITE(6,6)PROB2
      IF(PROB1.GE.0.5)WRITE(6,5)PROB1
    5 FORMAT(2X,'THE POSTERIOR PROBABILITY OF WALLEYE INTRODUCTION INTO
     *THIS RESERVOIR'/2X,'BEING UNSUCCESSFUL IS ',F8.6)
   6  FORMAT(2X,'THE POSTERIOR PROBABILITY OF WALLEYE INTRODUCTION INTO
     *THIS RESERVOIR'/2X,'BEING SUCCESSFUL IS ',F8.6)
C***********************************************************************
C     QUESTION TO BEGIN AT START OF PROGRAM
C***********************************************************************
      WRITE(6,7)
    7 FORMAT(/2X,'DO YOU WISH TO ENTER THE DATA FOR ANOTHER RESERVOIR'/
     *2X,'ENTER 1 FOR YES OR 2 FOR NO')
      READ(5,*)NUM
      IF(NUM.EQ.1)GOTO 8
      STOP
      END
```