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The Use of a Pattern Judgement Model to Assess Fish Habitat Suitability in Two Colorado Reservoirs

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ABSTRACT

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The suitability of two Colorado reservoirs to support an array of common fish species was assessed using a pattern judgement model. The model employs an expert panel to predict habitat suitability based on easily measured structural characteristics of the reservoir basin, local site climate, operational regime, and inflow characteristics. Model predictions, made before Kenney Reservoir was filled, indicated that common carp (*Cyprinus carpio*) and black crappie (*Pomoxis nigromaculatus*) would dominate the fish community in this reservoir. Sampling in the decade following completion of the dam substantiated this prediction. When additional species were added to the model and their likely performance in Kenney Reservoir evaluated, predictions of fish community composition closely followed trends observed in reservoir species composition. A proposed enlargement of an existing reservoir was evaluated with the model to predict what species might prosper as a result of the new configuration of the reservoir basin and inundation of new land areas. None of the 10 species evaluated were predicted to flourish in the new habitat provided by the enlargement. Predictions were consistent with the low abundance of these species in the existing reservoir and the probable lack of suitable habitat in the enlargement area. The pattern judgement model can be used to explore management options dealing with probable species performance as a function of the quality of available habitat using relatively static data gathered at low cost. The model's flexibility allows modification of input variable values to reflect local conditions or specific needs without altering model logic. Guidance is provided for adding more species to the model to broaden its applicability to other waters.

Key Words: reservoir fish habitat, pattern judgement model.

Reservoir habitats are often complex and are influenced by a host of interacting geologic, climatic, and geographic factors. Nested within these factors is a diverse set of soil associations, topography, land use, weather patterns, and hydrology that affect the ability of a reservoir to support a particular fish community (Thornton et al.1990). When human demands for power generation, irrigation, water storage, and recreation are imposed the extraordinary complexity of these aquatic systems quickly becomes evident.

Such complexities do not lend themselves to evaluation of the species-specific suitability of reservoir fish habitat with most mathematical scoring systems or those statistically derived (Aggus and Bivin 1982). These methods often fall short in describing reservoir

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habitats in meaningful or comprehensive ways that can guide fishery management decisions. It is here that judgements based on personal experience have the potential to enhance understanding of these complex interactions. McConnell et al (1982) introduced a different approach to reservoir habitat evaluation that uses a pattern judgement system to assess the suitability of a wide range of reservoir habitat types for a group of selected fish species. The system is based on a numerical pattern description of primary reservoir attributes, each derived from one or more of a much larger group of easily measured secondary attributes.

The pattern judgement model was originally designed as a screening tool to help fishery managers evaluate the suitability of potential reservoir sites during the early planning stages of reservoir development and as a means of comparing the outcomes of alternative construction plans. It soon became apparent that models based on pattern judgement could be used for a variety of fish management purposes. Not only could the fish habitat suitability of future reservoirs be evaluated, but existing reservoirs could also be assessed (Martinez 1997). The logic used to develop the model has also found utility in formulation of a stocking model for the grass carp (*Ctenopharyngodon idella*) in high elevation trout lakes in Colorado (Swanson and Bergersen 1988) and has been used to identify reservoirs in Colorado most suited for stocking with tiger muskellunge (*Esox lucius x Esox masquinongy*) (Koupal 1999). In this paper, we: 1) briefly summarize the methodology and logic of the pattern judgement system; 2) assess its performance in predicting the habitat suitability of a newly constructed main-stem impoundment (Kenney Reservoir, Colorado) and an existing reservoir being considered for enlargement (Elkhead Reservoir, Colorado); and 3) evaluate its potential applications.

Methods

Model Logic and Development

Because of the often rich interplay of habitat components and the multitude of habitat configurations a reservoir can assume, some species will do better in an impoundment than will others. This is not surprising because the importance of these interactions have long been recognized (Tonn et al. 1983), but, predicting the degree of success of a species in a complex environment becomes more problematic. While statistical or mathematical-based multivariate or other habitat analyses can summarize and simplify much of what is know about a reservoir, they lack the ability to accommodate human experience and insight in the evaluation of complex habitat patterns and how they influence a fish's performance. It is these complex patterns of interacting habitat conditions that are the key to a species success in any environment.

The pattern judgement approach introduced by McConnell et al. (1982, 1984) for reservoir habitat assessment employed the systematic use of expert opinion in a way reminiscent of earlier Delphi techniques (Dalkey et al. 1972). It had the advantages of procedural simplicity and ready availability of input data and relied heavily on the insight and experience of a panel of veteran fishery biologists to assess the meaning of various interacting habitat components relative to a select list of common fish species. Reservoir sites were described with a pattern of five digits, each depicting the suitability of one of three levels of what were referred to as primary attributes. Suitability levels were: 1=low; 2=medium ;and 3=high. The five primary attributes were: (A) temperature; (B) mineral turbidity; (C) nonliving cover; (D) maximum drawdown and timing; and (E) frequency of shallow coves. Primary attributes were derived from various combinations of secondary attributes - those basic chemical, physical, and operational conditions that can be used to describe any reservoir or reservoir site (Fig.1).

The range of secondary attribute values was divided into three segments representing lower, mid, and upper parts of the attribute's normal range for the geographic location under consideration. For example, the lower segment of the secondary attribute, growing season, was considered to be any growing season length less than 120 days. The mid range extended from 120 to 170 days and the upper segment was anything over 170 days. Growing season was an estimate of the number of days at the reservoir site between the last frost in the spring and the first frost in the fall (data available from local weather stations). The three growing season attribute levels were linked in a two-dimensional matrix with mean July air temperatures whose range had been similarly divided into three parts: < 15°C, 15-21°C, and >21°C. Each of the nine possible combinations in this 3x3 matrix was then assigned a score value of 1, 2, or 3.

Prior to applying secondary attributes to the derivation of primary attributes that make up the five-digit reservoir description, each species is assigned to one of three thermal tolerance groups : warmwater, coolwater, and coldwater. This preliminary delineation of species, which is determined by the expert panel, can result in more than one five-digit description for an individual reservoir. This outcome is possible depending on the specific fish species being considered and the derivation of the primary temperature score via the three distinct matrix scenarios for warmwater,

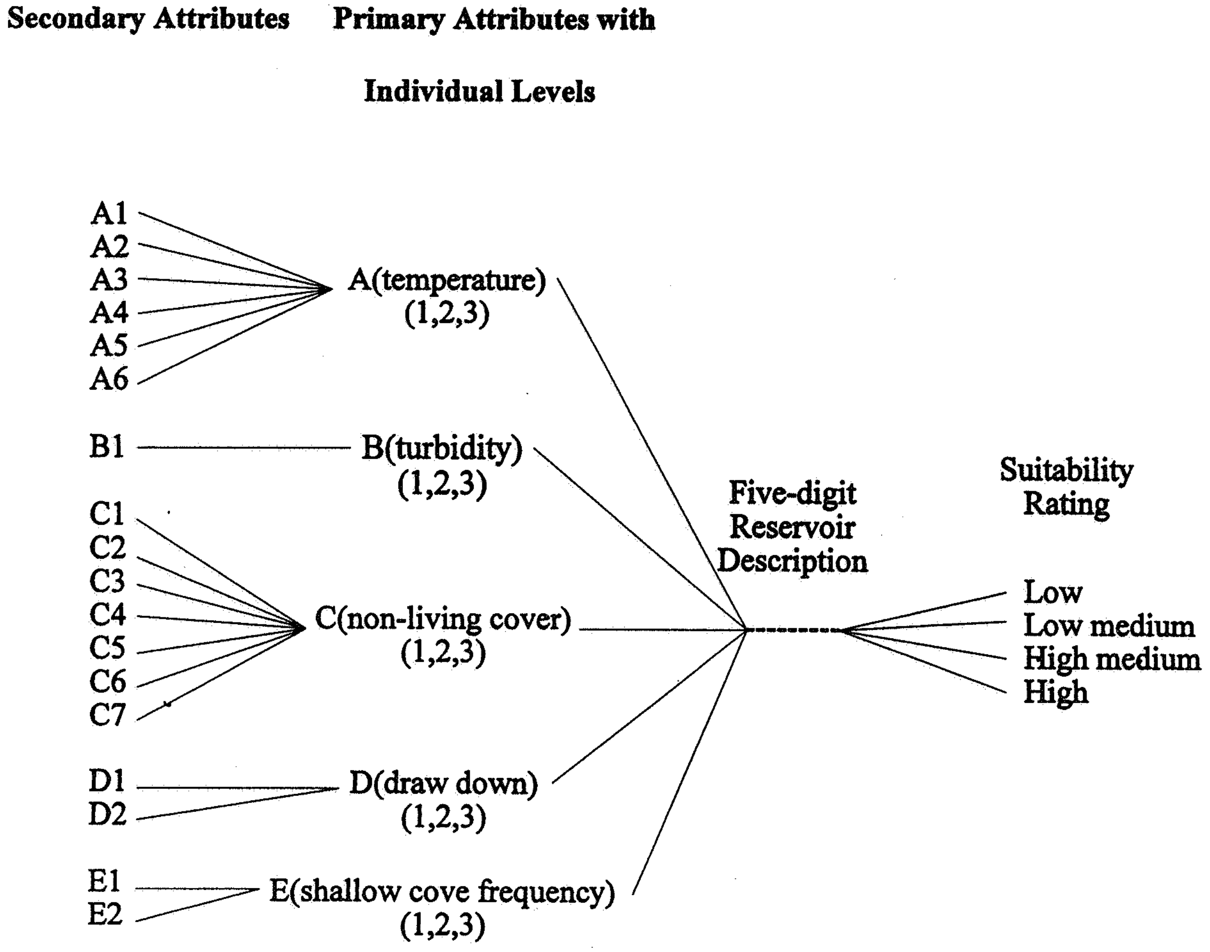

Figure 1.–Flow of system logic for deriving reservoir habitat suitability ratings from primary and secondary attributes (refer to Table 1 for secondary attribute descriptions). Each primary attribute is given the value of 1, 2, or 3 which is then entered into the appropriate position in the five-digit reservoir description. The secondary attribute Mean Depth (A6) was used twice, once in deriving the primary temperature attribute (A) and once in deriving the primary Shallow Cove Frequency attribute (E). Figure modified from McConnell et. al (1982.)

coolwater and coldwater species. For warmwater and coldwater species, length of the growing season and mean July air temperature are the only secondary attributes needed to derive a primary temperature score. To evaluate the temperature regime for a coolwater species, several additional attributes need to be included in deriving the primary temperature score. These are reservoir storage ratio, depth of outlet, mean depth, and wind fetch.

Each of the five primary attributes making up the 5-digit reservoir description was derived in a similar manner to that described above. In some cases as many as six or seven secondary attributes were used in a series of matrix comparisons to ultimately derive a single primary attribute score. Proceeding in this manner provided a means of combining much information in the derivation of each primary attribute used to arrive at the numerical reservoir description. Secondary attributes were not intentionally organized in any hierarchical manner.

Seventeen secondary attributes (as few as one to as many as seven per primary attribute) were incorporated in the initial model (Table 1). One secondary attribute, mean depth, was used twice in conjunction with other attributes in the derivation of the primary attribute scores for shallow cove frequency and as part of a stratification score that was used to derive a primary temperature score. The 5-digit number, composed of the five primary attributes (each with three levels), used to describe the reservoir had no intrinsic meaning. While the order of these attributes was unimportant, the pattern of habitat features (reservoir descriptions) represented by these five numbers (using three levels of each) was critical. Each reservoir description that emerged (there were 243 possible permutations {3^5}, ranging from lake description 11111 to 33333) was then evaluated by an expert panel in terms of how suitable each particular reservoir would be for a particular species, always keeping in mind the interacting nature (the pattern) of reservoir attributes. This panel

Table 1.–Secondary attribute values for Kenney and Elkhead reservoirs. Kenney Reservoir data adapted from McConnell et al. 1984.

Attribute	**Value**	
Temperature (A)	**Kenney Reservoir**	**Elkhead Reservoir**
A1 Growing season (days)	111	123
A2 Mean July air temperature (C)	22.8	19.0
A3 Storage ratio (volume{af}/avg. ann. discharge{af})	0.282	2.020
A4 Depth of outlet in relation to mean depth (z)	Below mid 1/3	Below mid 1/3
A5 Maximum fetch (km)	5.0	6.0
A6 Mean depth (m)	6.8	17
Turbidity (B)		
B1 Mineral turbidity (Secchi depth-m	0.5 to 1	>1
Nonliving Cover (C)		
C1 Areal extent of structure (%)	<10	<10
C2 Percent structure units on deepest half of bottom	<10	<10
C3 Mean height of structural units (m)	<1	<5
C4 Mean density of structural units (units/ha)	5	<50
C5 Linear extent of structure in deepest half of res. (%)	<10	between 10 & 30
C6 Linear extent of structure at full basin (%)	<1	<10
C7 Mean height of cliffs or shoals as % of mean depth	~ 100	>20
Maximum Drawdown and Timing (D)		
D1 Extent of maximum draw down(m/yr)	<2	6.4 winter
D2 Time of maximum draw down (month)	Nov. to Feb	Nov. to Feb.
Frequency of Shallow Coves (E)		
E1 Shoreline development factor	3.70	4.69
E2 Mean depth (m) {same as A6}	6.8	17

of two to six people assigned to each of the 243 five-digit lake descriptions a ranking of high, high-medium, low-medium, or low, reflecting the panel's collective opinion of how suitable each reservoir with its unique habitat features would be for the species in question. When a group of reservoir descriptions emerged with the same suitability rating, a set of simple logical rules for these similar reservoirs was generated that could be used to "screen" additional waters making the assignment of ratings less tedious. For example, a set of rules for assigning reservoir suitability ratings for yellow perch (*Perca flavescens*) include the following where A = temperature, B = mineral turbidity, C = non-living cover, D = drawdown extent and timing, and E = frequency of shallow coves:

Primary Attribute		Suitability Rating
If B = 1		Low
If not as above, and	A = 1 or D = 1 or B = 2	Low Medium
If not as above, and	C = 1 or E = 1 or A = D = 2	High Medium
If not as above		High

If a reservoir had a persistent turbidity problem (mineral turbidity score = 1), it is unlikely that yellow perch would prosper and the reservoir suitability for this species would always be assigned the lowest rating, regardless of what the other four primary attributes might look like. If turbidity was only a moderate problem (mineral turbidity score = 2), but the temperature score was 1, indicating a fairly cold shallow situation, and significant draw downs occurred at critical times during the year, the reservoir would be assigned a low medium rating. In a reservoir with a non-living cover score of 1 (lack of suitable cover) and not many shallow coves (shallow cove frequency score = 1) but where temperature and fluctuations were moderate, the reservoir would be assigned a high medium rating. If none of the above conditions existed, it would suggest that the reservoir was quite well suited for yellow perch and be assigned a high suitability rating.

Development of sets of rules greatly expedited the panel's ability to process the large number of reservoir descriptions. These rules were formulated as panel members worked through the assignment of suitability ratings. As reservoir descriptions were encountered that did not fit existing rule categories, new rules were developed. In general, a surprisingly brief set of rules was usually sufficient to accommodate all 243 reservoir descriptions for a given species. These rules, when inspected, provided the rationale behind each consensus decision derived by the panel and allowed one to backtrack to any decision point used to assign a suitability rating to each reservoir description. This ability to examine all components of the model greatly enhanced its utility and understanding of the habitat interactions that occurred in the array of reservoir descriptions generated. Contriving and then critically examining the robustness of the rules for each species became the principal task for the expert panel.

Personal expertise and experience as well as published literature and engineering and construction records were used to guide the judgement process for deriving each five-digit reservoir description. Habitat suitability ratings for each reservoir description were unique to each species because of the different ways various species could be expected to respond to similar habitat conditions. The original model included suitability ratings for five species: black crappie (*Pomoxis nigromaculatus),* white sucker (*Catostomus* commersoni), rainbow trout (*Oncorhynchus mykiss),* yellow perch , and common carp (*Cyprinus carpio).* To evaluate the suitability of a planned reservoir enlargement (described below), we expanded the model species list to include smallmouth bass (*Micropterus dolomieui),* largemouth bass (*Micropterus salmoides),* northern pike (*Esox lucius),* wild reproducing channel catfish (*Ictalurus punctatus),* and stocked channel catfish.

To assign habitat suitability ratings for these additional species, we increased the size of the expert panel (from two to six) to include additional veteran fish biologists familiar with the life histories and habitat needs of these new species. Two of the original panel members participated and guided the efforts of the new members. This panel functioned like earlier panels: it critiqued the importance of various habitat interactions and debated the merits of each reservoir description for each species, then generated consensus based classification criteria for deriving habitat suitability ratings.

Site Descriptions

Kenney Reservoir, formed by Taylor Draw Dam on the White River near Rangely, Colorado, first filled in 1985. This 250-ha impoundment was selected for initial model testing by McConnell et al. (1984) because it was typical of many dam sites being proposed on large rivers in the West at that time in response to region-wide energy development. The reservoir site also met the basic requirements for evaluation with the model: it was at a mid-latitude, total dissolved solids were less than 3000 mg$\cdot$L^{-1}, water quality was not unusual, the White River was not grossly polluted, and water levels in the proposed reservoir were not expected to fluctuate greatly. Fish present at the reservoir site while Taylor Draw Dam was under construction included an array of native and non-native species (Martinez 1986).

Elkhead Reservoir, an existing 178-ha reservoir located on Elkhead Creek, a tributary of the Yampa River in northwestern Colorado, is scheduled to be enlarged to 437 ha as part of a program to increase storage for late season releases into the Yampa River to off-set flow reductions from irrigation and other uses. These added flows are needed to enhance native fish winter habitat in the main stem of the Yampa River. Elkhead Resevoir once contained a self-sustaining population of smallmouth bass and a small remnant population of black crappie, bluegill (*Lepomis macrochirus),* largemouth bass, channel catfish, and northern pike. The reservoir never reached its expectations as a high-quality sport fishery. In 1992 the reservoir was drained for repairs, resulting in a loss of most of these game fish and effectively ending what limited sportfishing opportunities the reservoir provided. Sampling of the reservoir in the mid-1990's revealed low population levels of all species (Hydrosphere 1995).

With the proposed enlargement of the reservoir, angler hopes were focused on the inundation of new woody vegetation and a general improvement in fish habitat. To project the potential performance of possible sport fishes in Elkhead Reservoir, the proposed "new" enlarged reservoir site was evaluated with the model.

Fish Populations

Species composition and relative abundance information in the decade following completion of Taylor Draw Dam and the formation of Kenney Reservoir was obtained from Elmblad (1998), Martinez et al. (1994), Trammell (1991), and Trammell et al. (1993). Kenney Reservoir was intensely sampled by Trammell (1991) using seining, gillnetting, and electrofishing. Seining was done monthly from June through October at several sites along the shoreline. Gill nets were set monthly in all major habitats including shallow and deep coves, cliffs and sloping areas, at surface, bottom, and mid-depths. The reservoir was electrofished monthly at night from May through August 1989 and once in July, 1990. Elmbald (1998) sampled the reservoir annually from 1988 to 1994 using electrofishing, seining, gill and trammel nets. Interpretation of the status of the existing fish population in Elkhead Reservoir was derived from internal Colorado Division of Wildlife reports (Martinez 1997). Fish were sampled once or twice per year in 1993, 1999 (B. Elmblad, Colorado Division of Wildlife {CDOW], unpubl. data), and 2001 (B. Miller, Miller Ecological Associates, unpubl. data) using shoreline electrofishing, gill nets, seines, and trammel nets.

Secondary Attribute Acquisition

Secondary attributes for Kenny Reservoir (Table 1) were from McConnell et al. (1984). Secondary attributes for Elkhead Reservoir were obtained during two site visits, from discussions with engineers involved in the reservoir enlargement, and from review of reservoir enlargement planning and construction documents.

Results and Discussion

Kenney Reservoir

Prior to filling of Kenney Reservoir, McConnell et al. (1984) used their low effort model to assign five digit reservoir descriptions of 22132 for warmwater and coldwater fishes, and 32132 for coolwater fishes. These reservoir descriptions predicted that the reservoir would be best suited for carp (high rating). Black crappie and white suckers were expected to fare reasonably well (high medium rating) with yellow perch and rainbow trout habitat receiving a low medium rating (Table 2). When the two bass, northern pike, and catfish groups were added to the model species list, we were able to further assess the habitat suitability of Kenny Reservoir for these species. All of these species, with the exception of yellow perch, occurred in the drainage and were, for the most part, already present in the reservoir basin, albeit in very low numbers. Habitat ratings for largemouth and smallmouth bass and northern pike were all low medium. Model predictions indicated that as catfish habitat, either for stocked or wild fish, the reservoir would be rated as high medium.

In response to the expanding availability of new habitat and increased nutrients associated with the new reservoir, the fish population in Kenney Reservoir expanded rapidly. Soon after the reservoir filled (1985), black crappie reproduced successfully and within a decade constituted as much as 24% by number of the total fish collected during routine electrofishing and netting surveys by the Colorado Division of Wildlife (Elmblad 1998). In 1989 and 1990, Trammell reported extensive carp reproduction in the reservoir. During sampling between 1991 and 1994, carp numbers ranged from 10 to 41% of the total number of fish collected. White suckers, previously unreported in the White River drainage with the exception of one specimen from Utah, were first collected in the reservoir in 1989, gradually increasing to about 3% of the fish assemblage (Elmblad 1998). Yellow perch were not reported to be in the White River (Chart 1987, Trammell 1991). Rainbow trout numbers are artificially maintained in the reservoir by annual stocking, but Martinez et al. (1994) reported the frequent exodus of this species from the reservoir to downstream areas with little holdover from year to year.

Bass and northern pike were not common in the White River and were rare in collections (Martinez et al. 1994). In 1989, two largemouth bass were collected in Kenney Reservoir (Trammell 1991), but no additional bass have been collected and no evidence of reproduction has been observed. Despite initial concern that northern pike would escape from an upstream impoundment and proliferate in the White River, and in particular in Kenney Reservoir, none were found during extensive collections by Martinez et al. (1994). Although there have been occasional reports of anglers catching northern pike in the reservoir, it does not appear that pike have become established. Channel catfish occurred in the White River prior to the formation of Kenney Reservoir and by 1993-94, due to a single stocking in 1992, constituted about 10% of the reservoir fish community (Elmblad 1998).

As predicted, the Kenney Reservoir fish assemblage became numerically dominated by carp and black crappie within 10 years of filling. However, the closely related flannelmouth sucker *Catastomus latipinnis* averaged about 25% of the fish collected between 1988 and 1994. This sucker generally does well in impoundments and readily hybridizes with the white sucker, suggesting a likely overlap in habitat requirements. Channel catfish reproduction and recruitment has never been documented in the reservoir, but growth of fish stocked in 1992 has been exceptional, far exceeding catfish growth rates reported elsewhere in the region (Bill Elmblad, CDOW, pers. comm.) indicating that good habitat exists in the reservoir for this species.

None of the species for which habitat suitability was predicted to be low-medium were ever abundant in the river and when the reservoir was filled, they, as predicted, failed to establish noteworthy populations.

Table 2.–Habitat suitability ratings for Kenney and Elkhead reservoirs for 10 fish species based on model predictions. Ratings for the first 5 species are from McConnell et al. 1984. The second five are adapted from Martinez (1997). L = low, LM = low medium, HM = high medium, and H = high.

	RESERVOIR HABITAT RATING							
	Kenney Reservoir				Elkhead Reservoir			
Species	**L**	**LM**	**HM**	**H**	**L**	**LM**	**HM**	**H**
Black Crappie			X		X			
Carp				X	X			
White Sucker			X				X	
Yellow Perch		X					X	
Rainbow Trout		X					X	
Smallmouth Bass		X			X			
Largemouth Bass		X			X			
Northern Pike		X				X		
Channel Catfish (stocked)			X			X		
Channel Catfish (wild)			X		X			

Even rainbow trout that were artificially maintained by stocking failed to survive in the reservoir and grow well.

Elkhead Reservoir

The five-digit reservoir descriptions for Elkhead Reservoir were 13123 (warmwater fishes) and 23123 (coolwater and coldwater fishes). These habitat suitability ratings for the ten species evaluated indicated that even with the increase in structural components and infusion of nutrients associated with newly inundated areas, the enlarged reservoir would not be rated high for any of the species considered (Table 2). Habitat suitability ratings were low for five species (carp, black crappie, largemouth bass, smallmouth bass, and wild channel catfish), low-medium for two species (stocked channel catfish and northern pike), and high medium for white sucker, yellow perch, and rainbow trout. Although it is unusual for a reservoir to be this poor for this many common species, Elkhead Reservoir has a litany of problems that have limited its contribution to sportfishing in the area and these are not likely to change with the planned enlargement. The reservoir has a thermal regime that is neither optimum for coldwater nor warmwater species during the summer months, it has a persistent colloidal suspension that peaks during spring runoff as well as during other storm events, and nutrient input from the watershed is low (Martinez 1997). These were the driving factors that resulted in the generally low ratings generated by the model.

The predicted poor performance of the species evaluated was consistent with the marginal performance of most species found in the reservoir to date (Martinez 1997). Structural features likely to be inundated by the expansion are probably not greatly different than those inundated when the reservoir first filled in 1978. This would suggest that the new reservoir, from a fish habitat standpoint, will not be much different from the existing reservoir. Likewise, reservoir operations are not expected to change a great deal from the present (Hydrosphere 1995) so little improvement in overall habitat quality could be expected from different management scenarios (e.g., stocking, harvest regulations) that might benefit the fishery. While a short term improvement might be expected in the fish community in response to the "new reservoir phenomenon" as the dominant shrubland vegetation decomposes and adds nutrients and structural features to the system, the fish community that develops following reservoir enlargement should not be much different than that presently occurring in the reservoir. This contention was supported by the model predictions.

Summary and Conclusions

The original purpose for developing this model was to provide a means by which planners and managers could evaluate prospective reservoir sites based on the quality of fish habitat likely to occur in the reservoir and habitat needs of a select group of fish. Applying the model to assess the expansion of Elkhead Reservoir (basically a new reservoir) was a logical extension of model application. The model could be applied to existing reservoirs to evaluate their suitability for possible new species introductions or to guide management actions, including habitat enhancement, that might favor one or another species. Comparing model predictions might also facilitate model refinement by identifying needed, unneeded or additional attributes that could enhance model predictions. Introducing a new species into a well- established fish assemblage is not without risk. The vagaries of species interactions and climate can decrease the actual degree of success of a species. Validating the model in existing reservoirs with established fish assemblages would require extensive sampling with sonar, global positioning systems (gps), or other methodologies to confirm the presence and extent of some of the secondary attributes, particularly those associated with structural features of the reservoir. Construction records, contour maps, and preconstruction photos of the area could also be used to derive many of the secondary attributes.

The model can be applied to a wide range of reservoir types. Only those with very unusual water quality parameters or severe water level fluctuations need be excluded. We believe that the 243 possible reservoir descriptions encompass most, if not all, types of reservoirs likely to be encountered in mid-latitude regions. Broader application of this model is limited only by the number of species included for consideration. While adding additional species to the model list is not a trivial task, we would encourage users dealing with a different array of species to develop their own suitability ratings for what ever species they might desire. To do this requires the convening of a small group of people that are very familiar with the species in question and that have a basic understanding of the purpose and logic of the model.

When we added five new species in preparation for assessing Elkhead Reservoir, we gathered together a small group of species experts, briefed them on the mechanics of the model and proceeded to assign habitat rating to all 243 reservoir descriptions for each of these new species. Membership on the panel was based on the individual's knowledge of the habitat needs of one or more of the species being considered. The panel convened to deal with the five new species was composed of six fish biologists representing a diverse and extensive array of experience with these fish. Two of the members had developed the original model used to evaluate Kenney Reservoir. Others were research or management biologists. Jointly, their total fishery experience exceeded 125 years. Developing these models may require convening panels with this level of experience. We met five or six times to accomplish this and at each meeting reviewed and concurred on the outcome of our previous discussions. Between meetings, the project leaders formalized the agreed upon "rules" and organized the results for further review. While somewhat daunting at times, bringing expert judgement to bear on the problem quickly brought out any differences of opinion that were then discussed until a consensus could be reached. Many lively discussions ensued, but this was a remarkably painless process and an excellent learning tool for all involved. It also helped to identify information needs that could refine the decision-making process and improve the predictive capabilities of the model.

For anyone wishing to expand the model, we offer this cautionary note. The original model used five primary attributes with three levels each to generate 243 individual reservoir descriptions. Because each attribute level (1,2,or 3) has significance, these 243 descriptions are permutations, not combinations. Adding one additional primary attribute (still with 3 levels) would result in 729 descriptions. Adding one additional level (with five attributes) would result in 1024 descriptors. The number of judgements to ponder quickly increases to an unwieldy level as more attributes or attribute levels are added. Based on this, and our inability to develop more refined relationships between interacting habitat attributes having additional attribute levels, more than three secondary attribute quality levels did not seem justified. Asking a panel of interested, but probably volunteer, experts to contemplate greater than a few hundred reservoir descriptions for any given species would probably be met with some resistance.

Suitable physical habitat is a necessary condition for a species to flourish but other biological factors may be important. Species interactions such as competition and predation must also be factored into the final assessment of any habitat evaluation procedure. The existence of a large number of top predators in a system may preclude even the presence of some species that would otherwise do well. The original intent of this model was to predict the suitability of yet unbuilt reservoirs so the presence of competing species was not a major issue. When the model is used in a situation such as Elkhead Reservoir where a fish assemblage is already established, some consideration should be given to possible species interactions.

The pattern judgement model we used to assess habitat suitability in Kenney and Elkhead Reservoirs has several features that recommend its use for this purpose. Deciphering why a particular outcome or model prediction occurred is straightforward and easily done – there are no "black boxes." Any decision point can be reached by examining model rules or secondary attribute interactions with other attributes to determine exactly how any particular attribute score was derived.

The model is also very flexible; users can adjust secondary attribute value scales to suit their particular needs without altering the basic logic of the system. If additional information becomes available or differences in expert opinion occur, model rules can be changed or adjusted accordingly. This flexibility should encourage any prospective user to apply the model as is or proceed with some degree of confidence in tailoring it to their particular needs or locale.

Neither intuitive judgements nor formal mathematical or logical procedures (statistics) will guarantee the correctness of habitat suitability predictions (McConnell et al. 1984). Our intent in developing this model was to provide a structure in which well reasoned, well supported decisions about fish habitat can be made in the context of expert opinion. All decisions, whether based on experience (intuition) or formal mathematical procedures (statistics) are judgements and as such have the possibility of being incorrect.

Authors note: The seminal document upon which this paper is based [McConnell et al. 1984] is generally available in university libraries around the country. Copies can also be obtained from the senior author.

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