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APPLICATION AND TESTING OF A PROCEDURE TO EVALUATE TRANSFERABILITY OF HABITAT SUITABILITY CRITERIA

JEFF A. THOMAS

US Fish and Wildlife Service, 2800 Cottage Way, Sacramento, CA 95825, USA

and

KEN D. BOVEE

US Fish and Wildlife Service, 4512 McMurry Ave, Fort Collins, CO 80525, USA

ABSTRACT

A procedure designed to test the transferability of habitat suitability criteria was evaluated in the Cache la Poudre River, Colorado. Habitat suitability criteria were developed for active adult and juvenile rainbow trout in the South Platte River, Colorado. These criteria were tested by comparing microhabitat use predicted from the criteria with observed microhabitat use by adult rainbow trout in the Cache la Poudre River. A one-sided χ^2 test, using counts of occupied and unoccupied cells in each suitability classification, was used to test for non-random selection for optimum habitat use over usable habitat and for suitable over unsuitable habitat. Criteria for adult rainbow trout were judged to be transferable to the Cache la Poudre River, but juvenile criteria (applied to adults) were not transferable. Random subsampling of occupied and unoccupied cells was conducted to determine the effect of sample size on the reliability of the test procedure. The incidence of type I and type II errors increased rapidly as the sample size was reduced below 55 occupied and 200 unoccupied cells. Recommended modifications to the procedure included the adoption of a systematic or randomized sampling design and direct measurement of microhabitat variables. With these modifications, the procedure is economical, simple and reliable. Use of the procedure as a quality assurance device in routine applications of the instream flow incremental methodology was encouraged.

KEY WORDS Instream flow incremental methodology PHABSIM Habitat suitability criteria Transferability

INTRODUCTION

Habitat suitability criteria (HSC) are used in the instream flow incremental methodology (IFIM) to translate structural and hydraulic characteristics of streams into indices of habitat quality in the physical habitat simulation (PHABSIM) component of the methodology. Various parts of PHABSIM have been critically examined to determine the sensitivity of predictions of suitable habitat to errors in HSC (Shirvell, 1989), hydraulic simulation error (Osborne *et al.*, 1988) and the selection of different computer algorithms to simulate microhabitats (Gan and McMahon, 1990). Although each of these areas of quality assurance merits attention, perhaps the most controversial and potentially significant source of error lies in the selection of HSC that supposedly reflect the selection of microhabitat by a fish species in the stream under study. In some instances inability to agree on the HSC to be used in a study has resulted in a virtual deadlock between parties involved in water allocation issues. Each interest group may favour a different set of criteria with the belief that the results from IFIM will support the group's preferred alternative (Caldwell and Gowan, 1988).

Aside from the obvious problem of manipulating model input to achieve a preconceived output, there are many factors that affect fish behaviour in the selection of microhabitat. Orth (1987) summarized numerous studies suggesting that microhabitat selection by fishes can be altered by body size, risk of predation, presence and abundance of competitors, season, time of day and thermal regime. Other investigators have found that HSC can be affected by habitat availability in the stream from which the data on microhabitat use were derived (Morhardt and Hanson, 1988; Shirvell, 1989; Heggenes, 1990). Studies conducted by Smith and Li (1983), Fausch (1984) and Bachman (1984), imply that microhabitat selection by drift-feeding

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salmonids results from an energetic tradeoff between the amount of drift and the cost of maintaining feeding positions. Hence selection could also be influenced by food availability. Slaney and Martin (1987) even suggested that trout may change their selection of microhabitats depending on cloud cover.

Considering all of these factors, it is not surprising that HSC developed in two different streams are often dissimilar. The real question is whether HSC developed in one stream (the source stream) can be used to determine the quality and quantity of microhabitat in another stream (the destination stream). A simplistic definition of transferability is that fish should use higher quality microhabitats in greater proportion than they utilize lower quality microhabitats, if the HSC have correctly identified high and low quality. At least some of the controversy surrounding transferability can be attributed to the lack of a relatively simple, reliable procedure to test HSC to determine whether they adhere to this definition.

The objectives of this study were: (1) to develop and field test a procedure that could distinguish between HSC that are and are not transferable to a destination stream; (2) to determine the sample size necessary to produce reliable results; and (3) to suggest procedural modifications to increase the utility and practicality of the test for routine applications of IFIM.

DEVELOPMENT OF HABITAT SUITABILITY CRITERIA TO BE TESTED

The source stream for HSC tested in our study was a 15 km reach of the South Platte River below Cheesman Dam, near Deckers, Colorado. This reach was chosen because it was structurally and hydraulically diverse, contained high standing crops of the species of interest, and provided excellent water quality and underwater visibility. Based on guidelines provided by Bovee (1986), the Cheesman–Deckers reach of the South Platte appeared to be an ideal stream in which to develop HSC. The two dominant species present were rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*), both sustaining naturally reproducing populations.

Microhabitat utilization data were collected for active adult and juvenile rainbow trout during daylight hours (between 0900 and 1900 h MDT) in July and August 1988. Active fish were defined as those feeding or swimming in position. Data taken for fish at rest were not included in the database for the criteria. Juveniles were classified by size as individuals between 7 and 17 cm TL; adults were classified as individuals greater than 17 cm TL.

An equal effort sampling design was used to reduce bias associated with non-uniform microhabitat availability. The study area was stratified according to eight pre-defined habitat types (Table I). Equal areas of the eight habitat types were sampled once at a discharge of approximately 7 $m^3 s^{-1}$ and once at a discharge of approximately 17 $m^3 s^{-1}$. Individual sites in common habitat types were sampled once at either the high or low discharge. To maintain equal effort, it was necessary to sample sites in uncommon habitat types at both the high and low discharge.

Direct underwater observation (Li, 1988) was used to locate the positions of 163 active adult and 188 active juvenile rainbow trout. Depth and mean column velocity (measured at 0·6 of the depth) were recorded at each occupied location, as were cover type (no cover, visual isolation, velocity shelter, or combination), distance to cover, nose velocity (measured at 3 cm above the streambed) and substrate.

Criteria for depth, mean column velocity and cover were developed for both life stages. Non-parametric tolerance limits (Bovee, 1986) were used to develop HSC for depth and mean column velocity (Figure 1). The optimum range for a variable was defined as the interval encompassing the central 50% of the locations occupied by adult and juvenile rainbow trout. The suitable range for a variable was defined as the interval containing the central 95% of the occupied locations. The intervals between the optimum and suitable demarcations were considered to be habitable, but of lesser quality than the optimum range. We defined this intermediate interval as the 'usable' range. Histogram analysis was used to establish categorical criteria for cover. There was no clear selection for cover of any type by active adult rainbow trout, whereas active juveniles were often found using velocity shelters.

The criteria set labelled HSC-I (Figure 2) is for active adult rainbow trout and HSC-II is for active juvenile rainbow trout. The optimum ranges for the criteria are defined by the wide line portions of the graphs and the usable ranges by the thin line portions. Depths or velocities outside the boundaries of the usable

Table 1. Descriptions of habitat types sampled in the South Platte River

Low gradient riffle	No backwater effect. Water surface profile roughly parallel to thalweg profile and controlled by channel friction. Hydraulic gradient < 0·003. Cross-section uniform with depth < 45 cm at low flow
High gradient riffle	No backwater effect. Water surface profile often appears 'stair-stepped'. Hydraulic gradient > 0·003. Substrate consists mostly of boulders, with plunge pool formation among boulders below drops and small waterfalls. Cross-sections highly varied with isolated deep areas
Pocket water	No backwater effect for habitat type, but localized areas of backwater exist. Abundant random structural cover, usually scattered large boulders, creating many areas of low velocities (pockets) adjacent to high velocities. Depth and velocities change abruptly over short distances
Deep pool	Strong backwater effect from downstream hydraulic control. Maximum depth > 2 m at low flow. At least 25% of stream bed obscured by depth or structural cover
Moderate pool	Strong backwater effect from downstream hydraulic control. Maximum depth 1–2 m at low flow. At least 25% of stream bed obscured by depth or structural cover
Deep run/shallow pool with cover	Moderate to weak backwater effects. Pool depth at thalweg 0·5–1 m at low flow. At least 25% of stream bed area contains structural cover
Deep run/shallow pool with cover	Moderate to weak backwater effects. Pool depth at thalweg 0·5–1 m at low flow. Little or no structural cover present
Chute	Very deep, narrow channel incised in bedrock. Depths exceed 3 m at low flows, with moderate to high velocities at all but the lowest flows. Cover is sparse to non-existent

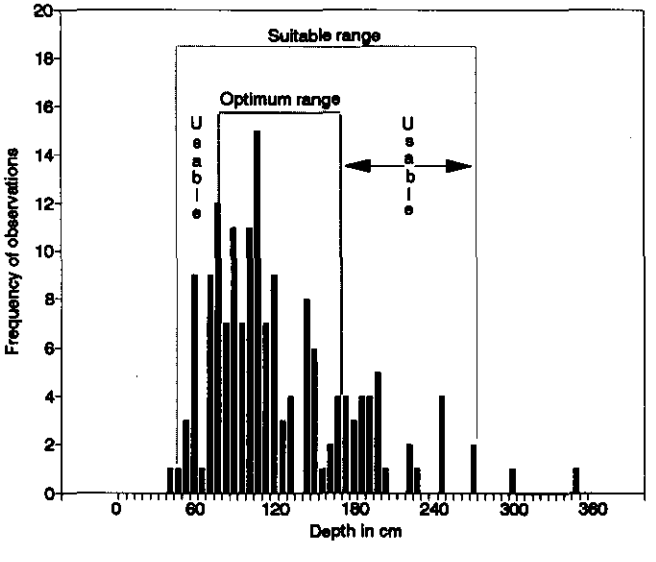

Figure 1. Relation between frequency distribution of depths utilized by active adult rainbow trout in the South Platte River and habitat suitability criteria developed by non-parametric tolerance limits. Optimum range corresponds to central 50% of observations and suitable range to central 95%. Usable ranges fall between limits of optimum and suitable ranges

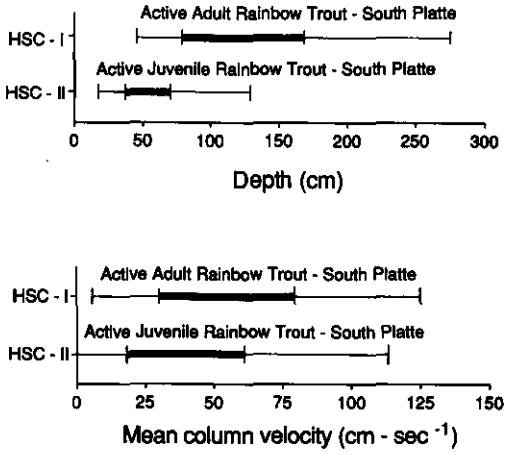

Figure 2. Optimum (wide line) and usable (thin line) ranges of HSC tested against observations of active adult rainbow trout in the Cache la Poudre River, Colorado. HSC-I = active adult rainbow trout, South Platte River ($N = 163$; HSC-II = active juvenile rainbow trout, South Platte River ($N = 188$)

ranges at either end of the graph were considered unsuitable. These criteria are consistent with the results of other workers (Lambert and Hanson, 1989; Heggenes, 1990) who have found that salmonids frequent areas of greater depth and velocity as they grow larger.

STUDY AREA

A 9 km section of the Cache la Poudre River, located approximately 75 km west of Fort Collins, Colorado, was chosen as the destination stream. This reach was selected because of its physical and biological similarity to the Cheesman–Deckers reach of the South Platte. The Cache la Poudre is approximately the same size as the South Platte and the same habitat types are present in similar proportions in both streams. The two dominant species in the Cache la Poudre are also naturally reproducing brown trout and rainbow trout. Based on diving observations, the ratios of brown trout to rainbow trout in the two streams are similar and the two streams are managed under comparable special fishing regulations.

OBJECTIVE 1: ABILITY TO DISTINGUISH TRANSFERABLE AND NON-TRANSFERABLE HABITAT SUITABILITY CRITERIA

Methods

The first objective of this study was to develop and test a procedure that was sufficiently rigorous to distinguish between transferable and non-transferable HSC. Four study sites were established in the Cache la Poudre study area, each describing a major category of available habitat. Each study site was approximately 60 m long and 30 m wide. A measurement grid of equal-sized cells was established at each site, and to the extent possible, cells were uniform (3 m long and 1 m wide) across all sites. A horizontal survey of each site was conducted by range and bearing methods to determine the relative positions of transects and cell boundaries. Bed elevations at the lateral cell boundaries were determined by differential levelling and water surface elevations were surveyed at 0·7, 4·4, 7·1 and 20 $m^3 s^{-1}$ to develop empirical stage–discharge relationships for each transect. Measurements of cover, substrate and mean column velocity were made at approximately 7·1 $m^3 s^{-1}$.

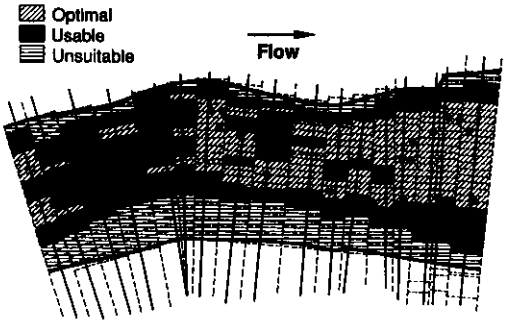

Figure 3. Scale planimetric map of shallow pool habitat type, Cache la Poudre River, showing correspondence between composite suitability and occupancy by active adult rainbow trout (indicated by dots). Composite suitability calculated for a discharge of $11{\cdot}4\,m^3\,s^{-1}$ using HSC-I

A three person team observed fish by diving in each site using the techniques described by Li (1988). The discharge at the time of diving was approximately $11.4\,m^3\,s^{-1}$. Locations occupied by one or more active adult rainbow trout were marked with a weighted, numbered tag. At the conclusion of the dive, the position of each marker was surveyed using the same horizontal reference system used during the initial site survey. In addition, all microhabitat variables associated with the tag locations were measured directly.

The IFG4 hydraulic model (Milhous *et al.*, 1989) was used to simulate the cell by cell hydraulic characteristics of each site at a discharge of $11{\cdot}4\,m^3\,s^{-1}$ (the discharge at which fish were observed). Cell depths and mean column velocities were calculated in two different ways: by averaging predicted depths and velocities at the cell boundaries and by predicting depths and velocities at the cell centroid. There was little difference between depths and velocities simulated at the centroid and those averaged from the cell boundaries at the four sites. Consequently, only the simulations based on the cell centroids are reported here for brevity.

Composite suitabilities were calculated for each cell, once using HSC-I and once using HSC-II. The composite suitability for a cell was classified as optimum if the individual suitabilities for depth, velocity and cover were all optimum. If the suitability for any variable was unsuitable, the composite suitability for the cell was classified as unsuitable. A cell was classified as usable if any or all of the variables for the cell fell into the usable category. Cell coordinates and tag locations were transferred to scale planimetric maps of each study site to overlay composite suitability with cell occupancy (Figure 3).

Data from all sites were combined to obtain counts of occupied and unoccupied cells of unsuitable, usable, or optimum composite suitability. A fourth classification, defined as suitable, was created by combining the usable and optimum classifications. The counts were cross-classified in two 2×2 contingency tables: one table to test suitable versus unsuitable classifications (Figure 4) and one table to test optimum versus usable classifications (Figure 5).

A one-sided χ^2 test (Conover, 1971) was used to test for random or non-random selection of microhabitat conditions by fishes. The test statistic T is given as

$$T = [N^{0{\cdot}5}(ad - bc)]/[(a+b)(c+d)(a+c)(b+d)]^{0{\cdot}5}$$

where a = number of occupied optimum (or suitable cells; b = number of occupied usable (or unsuitable) cells; c = number of unoccupied optimum (or suitable) cells; d = number of unoccupied usable (or unsuitable) cells; and N = total number of cells.

Two null hypotheses, listed on Figures 4 and 5, were tested. For a set of HSC to be considered transferable, a stipulation was imposed that both null hypotheses must be rejected at the 0·05 level of significance. As this

	Suitable	Unsuitable	Total
Occupied	A	B	A + B
Unoccupied	C	D	C + D
Total	A + C	B + D	N

H_0 : Suitable cells will be occupied in the same proportion as unsuitable cells.

H_1 : Suitable cells will be occupied in greater proportion than unsuitable cells.

Figure 4. Contingency table format and hypotheses for one-sided χ^2 test of suitable versus unsuitable classification of microhabitat. The suitable clasification is defined as the combined optimum and usable classifications

is a one-sided test, the significance levels of T are determined from the standard normal distribution table, rather than from the χ^2 table (Conover, 1971).

Active adult rainbow trout were chosen as the evaluation species and life stage. We hypothesized that HSC-I would have a high probability of transferring to the Cache la Poudre owing to the physical and biological similarities of the two streams. We also postulated that the microhabitat requirements of juvenile trout were sufficiently different from those of adults (Lambert and Hanson, 1989) that HSC-II would not be transferable when applied to adult trout.

Results

HSC-I were determined to be transferable to active adult rainbow trout in the Cache la Poudre. The null hypotheses for both the optimum versus usable and the suitable versus unsuitable tests were rejected (Table II). HSC-II, developed for juvenile rainbow trout, were determined to be non-transferable when applied to adults in the Cache la Poudre. Both tests resulted in failures to reject the null hypothesis (Table II).

OBJECTIVE 2: DETERMINE EFFECTS OF SAMPLE SIZE ON TEST RELIABILITY

The sample sizes of occupied and unoccupied cells, as well as the ratio between the two, are important determinants of T, the test statistic. Under objective 1, we collected data on a total of 77 occupied cells and 1968 unoccupied cells. Our second objective was to determine how much these two sample sizes could be reduced without adversely affecting the reliability of the procedure.

	Optimal	Usable	Total
Occupied	A	B	A + B
Unoccupied	C	D	C + D
Total	A + C	B + D	N

H_0 : Optimal cells will be occupied in the same proportion as usable cells.

H_1 : Optimal cells will be occupied in greater proportion than usable cells.

Figure 5. Contingency table format and hypotheses for one-sided χ^2 test of optimum versus usable classification of microhabitat

Table 2. Transferability test statistics (T and probability of accepting H_0) for HSC-I and HSC-II, tested with observations of active adult rainbow trout in the Cache la Poudre River. Values in italics indicate failure to reject H_0, resulting in rejection of HSC

	Optimum/usable		Suitable/unsuitable	
Criteria set	T	P	T	P
HSC-I	4·477	< 0·001	5·755	< 0·001
HSC-II	*−1·123*	*0·869*	*0·769*	*0·221*

Reliability is reduced when the probability of committing either a type I or type II error increases. A type I error is committed when a null hypothesis that should have been accepted is rejected. A type II error results when a null hypothesis that should have been rejected is accepted. Type I errors are considered more critical in IFIM applications because they can result in the acceptance and use of non-transferable criteria in a destination stream. In contrast, a type II error would result in the rejection of transferable criteria, which would be inconvenient but not as serious as using the wrong criteria in a study.

Methods

Occupied and unoccupied cells were randomly subsampled from the total Cache la Poudre database to determine the effects of sample size on test reliability. Each subsampling consisted of a combination of occupied cells ranging from 15 to 75 and of unoccupied cells ranging from 100 to 800. Unoccupied cells were sampled equally from each habitat type in compiling the total subsample (e.g. 25 random samples from each habitat type to achieve a total of 100 unoccupied cells).

The randomly sampled combination of occupied and unoccupied cells in each suitability class was then cross-classified, counts entered into the appropriate contingency tables and T-values for the optimum-usable and suitable-unsuitable tests calculated. A type II error was recorded whenever a particular combination of sampled cells resulted in $T < 1{\cdot}6449$ (the rejection value for T at the 0·05 level of significance) using HSC-I. A type I error was tallied when subsamples using HSC-II resulted in $T \geq 1{\cdot}6449$. This procedure was repeated 100 times for each combination of occupied and unoccupied cells.

Results

Type II errors were negligible when a combination of 55 occupied and 200 or more unoccupied cells were used in the test (Figure 6). The probability of committing a type II error increased rapidly when the number of unoccupied cells was reduced to 100, regardless of the number of occupied cells. The incidence of type II errors also increased dramatically as the number of occupied cells was reduced to 35 or fewer, regardless of the number of unoccupied cells used in the test.

The trend in type I errors (Figure 7), although more erratic, was similar to the pattern of type II errors. Type I errors occurred infrequently when combinations of at least 55 occupied and 200 unoccupied cells were used in the test. As the number of occupied cells was reduced, the incidence of type I errors increased, although not as sharply as type II errors. These results suggest that type I errors are more strongly related to the number of occupied cells than to the number of unoccupied cells.

DISCUSSION

Theoretical considerations

Historically, the method of choice for evaluating HSC has been the abbreviated convergence method (Bovee, 1986). This method consisted of comparing HSC for individual variables with histograms developed from fish observations in the destination stream. Criteria were considered transferable if there was good correspondence with the histograms. Owing to small samples from the destination stream and physical

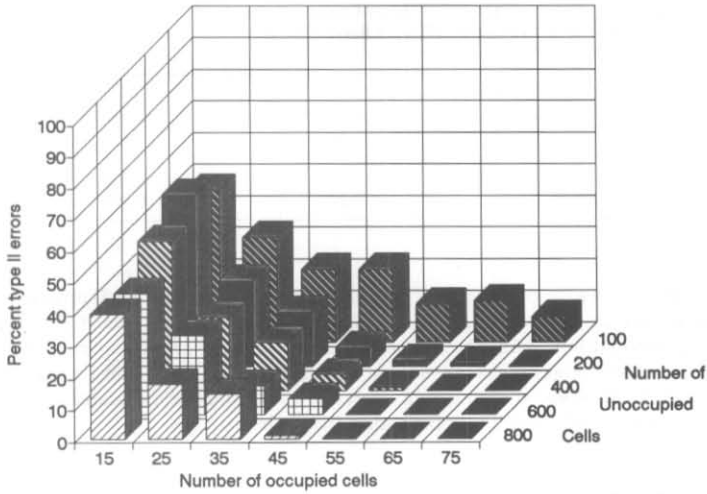

Figure 6. Percentage of trials resulting in type II errors with various combinations of randomly subsampled occupied and unoccupied cells

differences with the source stream, however, good agreement was rare. The investigator was left with the insecurity of knowing that there were apparent differences in microhabitat use between the two streams, but not knowing if the HSC were transferable.

The procedure described in this study differs from the abbreviated convergence method in several important ways. This procedure accounts for microhabitat availability as an integral part of the method. The paramount consideration in evaluating HSC is whether the species' selection of microhabitat is fundamentally the same in the source and destination streams, not whether the two streams are physically similar. Accounting for unoccupied microhabitat improves the ability of the investigator to distinguish behavioural differences from dissimilarities in stream characteristics.

The subjectivity associated with visual comparisons is reduced through the statistical hypothesis testing utilized in this procedure. Using the one-sided χ^2 test, HSC are evaluated on the basis of non-random selection of higher quality habitats over those of lesser quality. The fact that a destination stream may have very little optimum microhabitat is poor justification to redefine what is optimum for the species. However, this is often what is done when HSC are evaluated by the abbreviated convergence method. Statistical hypothesis testing allows the investigator to make the distinction between an imperfect fit and non-transferability.

In contrast with the abbreviated convergence method, this test is performed on the combined suitability of several microhabitat variables, rather than evaluating criteria for one variable at a time. This adds a multivariate dimension to the test. To obtain positive results (e.g. HSC-I in the Cache la Poudre), not only must the HSC for the individual variables be accurate, the variables selected to determine composite suitability must also be correct. Omission of a key variable or addition of superfluous variables may produce negative test results (i.e. rejection of the criteria) even though the HSC for individual variables might have been accurate.

Practical considerations

The third objective of our study was to streamline the procedure, without compromising its reliability, to facilitate its use in routine applications of IFIM. Data collection for the field test conducted on the Cache la Poudre, not including development of the criteria from the South Platte, required approximately 18 person

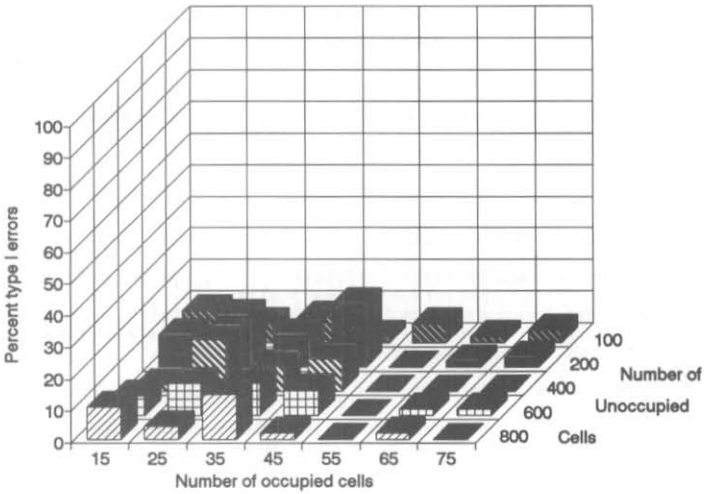

Figure 7. Percentage of trials resulting in type I errors with various combinations of randomly subsampled occupied and unoccupied cells

months of effort. Such a commitment of time and staff costs would make the procedure unfeasible for most routine applications of IFIM.

A significant result of our study was that test reliability remained high with as few as 55 occupied and 200 unoccupied cells. The reduction in the number of unoccupied cells is particularly important. Total coverage of unoccupied cells requires the establishment of permanent sites and, usually, reliance on simulation modelling to determine cell attributes. Simulation modelling, regardless of how well it is performed, will always introduce an element of error into the test. By reducing the number of unoccupied cells needed to conduct the test, random or systematic sampling designs can be used in place of permanent cells and study sites. The need to rely on simulation modelling is likewise eliminated, because cell attributes can be measured concurrently with the determination of cell occupancy.

Under the guidelines of using a random or systematic sampling design, directly measuring cell attributes and collecting data for the specified number of samples, the time and effort required to perform transferability tests of HSC may be reduced significantly. Following the modified procedure in the Cache la Poudre, the transferability test we performed could have been completed in approximately 5% of the time required under the original study design. A reduction of this magnitude should not be expected if there is a low population density of the species under study in the destination stream, because it will take longer to obtain the requisite number of occupied samples. Even where a species is scarce, however, a considerable time saving should still be anticipated using the modified procedure; in fact, it is likely that it would be unfeasible to test HSC for a rare species using the 'total coverage' approach. Additional experimentation is encouraged to determine whether these recommendations will result in satisfactory test performance for other species and stream settings. We also encourage IFIM users to consider implementation of this modified procedure in operational applications of the methodology. Ensuring that the HSC are applicable to the stream under study will impart greater confidence in results produced by the model.

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