APPLICATIONS OF RESOURCE SELECTION FUNCTIONS IN FISHERIES SCIENCE

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Abstract: Application of resource selection functions is a recognized approach for assessing habitat and food requirements of animals within a population. However, there is no standardized approach for assessing resource selection of fishes among fisheries scientists. My purpose was to assess how fisheries scientists have approached the study of resource selection since 1990. A total of 86 resource selection papers published in the three prominent North American fisheries science journals were identified, 74 assessing habitat selection, 11 assessing food selection, and one addressing both habitat and food selection. Common approaches to the assessment of categorical habitat data included indices of selection, preference curves, chi-square goodness-of-fit tests, or log-likelihood ratio tests. Continuous habitat data were commonly analyzed with logistic regression, linear regression, or nonparametric tests. Food selection studies were primarily based on categorical data assessed with indices of selection.

Key words: Resource selection, fish, habitat, food.

Fisheries management can be defined as the manipulation of aquatic organisms, aquatic environments, and their human uses to produce sustained benefits for people (Nielsen 1999). Determining which resources are selected by fishes provides insight into the resources needed for survival (Manly et al. 2002). It is assumed that fish will select resources that best enable them to satisfy their life history requirements. One approach to defining resource selection is to compare used resources to available or unused resources, and to assume that selection occurs when certain resources are used disproportionately to their availability. Manly et al. (2002) described numerous approaches to the assessment of resource selection by animals, most of which have application to the study of resource selection by fishes. Detection and measurement of the degree to which resources are selected or avoided is often an objective of fisheries research. I was not aware of previous reviews that have described how fisheries scientists approach the design and analysis of resource selection studies, so my purpose was to assess how fisheries scientists have approached the study of resource selection by fishes.

METHODS

For the period of 1990 through 2002, I reviewed the three prominent North American fisheries science journals: (1) *Transactions of the American Fisheries Society*, (2) *North American Journal of Fisheries Management*, and (3) *Canadian Journal of Fisheries and Aquatic Sciences*. Titles and abstracts were used to identify articles that were likely to address resource selection. These papers were read and three criteria were used to identify papers where resource selection was actually addressed: (1) a single species of finfish was the target of the research; (2) resource selection was assessed by comparing any two of three sets of habitat or food data--used, unused, or available; and (3) measurements were at the population level where it could be assumed that all animals in the population has access to the same available resources. These criteria excluded studies where only habitat use or diet were described; studies where presence and absence or abundance of a species were related to measured habitat features among different populations; laboratory experiments in which resource use was compared among distinct treatments; and comparative studies of habitat use or diet before and after a manipulation of the environment.

Papers that met the criteria as resource selection studies were categorized as habitat or food selection studies. Sampling protocols were categorized following Manly et al. (2002) as: (1) SP-A, available resource units were either randomly sampled or censussed and resource units used by animals were randomly sampled; (2) SP-B, available resource units were either randomly sampled or censussed and a random sample of unused resource units was taken; or (3) SP-C, unused and used resource units were independently sampled. Similarly, the study designs were categorized following Manly et al. (2002) as: (1) Design I, measurements were made at the population level, and used, unused, or available resource units were sampled or censussed for the entire study area, but individual animals were not identified; (2) Design II, individual animals were identified and the use of resources was measured for each, but availability was measured at the population level; or (3) Design III, individual animals were identified, and at least two of the three sets of resource units (used, unused, or available) were sampled or censussed. The analytical approaches for categorical and continuous data were described separately for habitat and food selection studies.

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RESULTS

A total of 86 resource selection studies were identified, and 74 were habitat selection studies, 11 were food selection studies, and one addressed both habitat and food selection. The majority of resource selection studies were found in the *Transactions of the American Fisheries Society* (43 papers) with about half as many in both the *North American Journal of Fisheries Management* (21 papers) and *Canadian Journal of Fisheries and Aquatic Sciences* (22 papers). From 1992 through 2002 a mean of 6.6 papers/year were published that addressed resource selection with no apparent temporal trends.

All of the studies used sampling protocol SP-A where available resource units were either randomly sampled or censussed and used resource units were randomly sampled. Habitat selection studies were of two designs with 45 Design I and 30 Design II studies. Design I studies generally involved systematic sampling of habitat over a reach of stream or segment of lake shoreline, and measurement of habitat at locations were fish were observed. All Design II studies used radio or ultrasonic telemetry to identify habitat used by individual fishes. All food selection studies were Design II.

Habitat Selection

Categorical data.--Indices of selection were used in 14 of 74 habitat selection studies (Table 1). Nine different indices of selection were used to assess selectivity, six of which were described and used previously in ecological research. Five studies applied the Strauss (1979) index (Clapp et al. 1990; Bruno et al. 1990; Beyers and Carlson 1993; Pert and Erman 1994; Matthews 1996b) and three studies used the Jacobs (1974) index (Roper et al. 1994; Matthews 1996b, Bradford and Gurtin 2000). The indices of Chesson (1978), Vanderploeg and Scavia (1979), and Ivlev (1961), and the percent similarity index (Krebs 1989), were each used in a single study (Moen et al. 1992; Gipson and Hubert 1993; DeVries et al. 1998; Healy and Longarich 2000). Among the other three indices, one was unique to recent fisheries literature (Bisson 1988; Jacober et al. 1998), the second was simply the quotient of the proportion used divided by the proportion available (Knapp and Vredenburg 1996), and the third was an index based on ranks of used and available habitat categories (Kynard 2000).

Preference curves were one of the most common approaches to assessment of use and availability data (Table 1). Preference curves were developed initially for incorporation into instream flow and habitat suitability modeling techniques of the U.S. Fish and Wildlife Service (Bovee 1982). Because there is much attention given to the management of instream flow in the fisheries literature, preference curves are commonly developed and published. Curves are developed for specific life stages (i.e., spawning, fry, juvenile, adult) for each of a small number of habitat features (i.e., depth, velocity, and substrate). Suitability indices are calculated from proportional frequency-of-use distributions by dividing the proportional use for an interval on a resource axis by the proportional availability for that interval. The suitability distribution is generally standardized by dividing the suitability value in each interval by the maximum suitability value so that the standardized suitability can vary from zero (unsuitable) to one (optimal). The histograms of standardized suitabilities are often smoothed to create preference curves along the resource axis. Preference curves are subsequently used as criteria in instream flow or habitat suitability modeling. However, preference curves have also been used as a method for describing resource selection with modifications to meet specific research objectives (Bozek and Rahel 1991; Brown and MacKay 1995; Guay et al. 2000).

The chi-square goodness-of-fit test was the most frequently used test of resource selection with categorical data (Table 1) being used in 14 of the 74 habitat selection studies. The observed frequencies of fish in habitat classes (used) are compared to observed frequencies of habitat classes (available) in the study area as a test of resource selection (Manly et al. 2002). Several researchers combined the chi-square goodness-of-fit test with Bonferroni's (95%) confidence intervals (Beyers et al 1984) to better identify selection for individual classes of habitat (Lobb and Orth 1991; Nakamoto 1994; Swanberg 1997; Jacober et al. 1998; Quist et al. 1999; Snedden et al. 1999; Bradford and Gurtin 2000; Muhlfeld et al. 2001). Log-likelihood ratio tests were applied in four studies.

Assessment of temporal trends in the analysis of categorical data from 1990 through 2002 suggested that the use of selection indices has declined, but applications of preference curves and chi-square goodness-of-fit tests have remained rather consistent.

Continuous data.--Logistic regression was the most commonly used (10 papers) statistical test with continuous data (Table 1). Logistic regression was used to determine differences in habitat features of sampled sites with and without fish in several studies (Walters and Wilson 1996; Monzyk et al. 1997; Childs et al. 1998; Geist et al. 2000; Welsh et al. 2001). More frequently, it was used to compare habitat measured at locations of fish to habitat available in the study area. Both univariate and multivariate, stepwise procedures were used.

Linear regression was applied to model relations between measures of fish abundance in sampling units to habitat measurements in the units among seven habitat selection papers (Table 1). Both univariate and multivariate procedures were applied.

Comparisons of used and available habitat features used were commonly made with nonparametric two-sample tests, particularly the Mann-Whitney *U*-test (9 papers; Table 1).

Two applications of a *t*-test to compare used and available habitat features were found (Matthews 1996a, 1996b). In these two cases the mean proportion of use of a habitat class among individual fish was compared to the proportional availability of the habitat class in the study area.

A few examples of comparisons of measurements of used and available habitat resources among several classes were found. Nonparametric methods were applied in lieu of two-way ANOVA in two cases (Zigler et al. 1999; Beyers and Carlson 1993) and the general linear model was used in one case (Essington and Kitchell 1999).

Some temporal trends from 1990 through 2002 were evident in approaches to analysis of continuous data. Papers applying logistic regression were identified only after 1993 and uses of nonparametric statistics were found only after 1994. The frequency of applications of logistic regression increased between 1994 and 2002.

Food selection

Categorical data.--Indices of selection were the only statistics used with categorical food data in nine of 11 papers where food selection was assessed (Table 1). Five different indices were applied, all of which have been described and used previously in ecological research. The Chesson (1978) index was used in three papers (Goshorn and Epifanio 1991; Schael et al. 1991; Limburg et al. 1997); the Strauss (1979) index was used in two papers (Dahl-Hansen et al. 1994), and the classic Ivlev (1961) index was applied in two papers in the early 1990s (Rondorf et al. 1990; Naesji et al. 1991). The Morisita (1959) index and a simplified form of it (Krebs 1989) were used in one paper each (Angradi and Griffith 1990; Nielsen 1992). Eight of nine food selection papers in which indices of selection were used were published 1990-1994, with one paper in 1997.

Continuous data.--Length distributions of food items in stomachs and in samples of available food resources were compared with Kolomogorov-Smirnov two-sample tests in two papers on prey selection (Poe et al. 1991; Wilhelm et al. 1999). In one study correlation analysis was used to examine relationships between abundance of prey species and the proportion of the diet composed of particular prey species among different depth strata and sampling months (Elrod and O'Gorman 1991).

DISCUSSION

While 86 resource selection studies were identified from 1990 through 2002 in the three prominent North American fisheries science journals, these papers represented a very small proportion of the total number (approximately 5,000) of papers in the three journals, as well as the proportion of articles on habitat and food needs of fishes. Many other articles on habitat and food use involved comparative studies among populations, seasons, or sizes of fish within a species; comparisons among species; comparisons before and after a manipulation of some type; or controlled laboratory experiments.

Opportunities for resource selection studies in fisheries science may be less frequent than in wildlife science. One reason may be a tradition of applying comparative studies of habitat use among species, life stages, or different populations when addressing problems regarding resource needs in fisheries research. A second reason may be that management focuses on large areas, such as watersheds or geographic regions that encompass many populations, so appropriate research designs to test habitat selection are not included. Another reason may be that accurate measurement of habitat use among many species of fishes, particularly small, cryptic species or large, migratory species, is difficult or impossible to measure with available techniques.

Very few food selection studies were found in the fisheries literature, and those that were conducted were generally part of more comprehensive ecological studies. One limitation in food selection studies is accurate measurement of food availability. Accurate measurement of food availability is possible for zooplanktophagic fishes, but it can be quite difficult for insectivorous and piscivorous species. It appears from observations during this assessment that much of the research involving food resource use in fisheries science has progressed to the application of energetics modeling.

Among the resource selection studies in the fisheries literature, many used only descriptive statistics in the form of selection indices or preference curves and they did not perform statistical tests to determine if statistically significant selection or avoidance occurred. Manly et al. (2002) described five statistical modeling procedures for the analysis of resource selection: (1) simple sample comparisons, (2) logistic regression, (3) log-linear models, (4) proportional hazard models, and (5) general linear models. Among these five classes, numerous examples of sample comparisons and logistic regression were identified, and one application of the general linear model was found. No applications of log-linear modeling or proportional hazard modeling were identified. Overall, fisheries scientists have used descriptive indices and relatively simple statistical models in the assessment of resource selection.

Very few papers in which habitat selection was modeled subsequently used the models to predict spatial patterns of occurrence or abundance of the modeled species. However, examples were found where logistic-regression models were applied in this manner (Hayes and Jowett 1994; Knapp and Preisler 1999; Geist et al. 2000; Tiffan et al. 2002). More frequent use of habitat resource selection functions can be anticipated among fisheries scientists as landscape-scale approaches to research and management increase.

A shortcoming of resources selection studies in the fisheries literature was the failure to test or assess models. Manly et al. (2002) and Anderson and Burnham (2002) have presented approaches for testing and assessing models that are not commonly used by fisheries scientists. No examples of techniques for selection of models, such as Akaiki's information function, were used among the array of resource selection studies that were identified.

There were many studies in the North American fisheries literature that evaluated relations between abundance of fishes and habitat features among populations, such as an array of lakes or streams in a geographic area, using linear regression. Similarly, the presence and absence of fish species has been related to habitat features among populations using logistic regression. While not meeting the definition of resource selection studies used in this paper, they yield insight as to the resource needs of fishes and they utilize analytical techniques that have application to studies of resource selection at the population level.

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Table 1. Summary of the analytical approaches used in resource selection studies identified in the three prominent North American fisheries science journals between 1990 and 2002.

Analytical approach	Number of studies	Applications in fisheries
		Habitat Selection
Categorical data		
Indices of selection	14	*Design I*: Gipson and Hubert 1993; Pert and Erman 1994; Roper et al. 1994; Knapp and Vredenburg 1996; DeVries et al. 1998; Healy and Longarich 2000 *Design II*: Bruno et al. 1990; Clapp et al. 1990; Moen et al. 1992; Beyers and Carlson 1993; Matthews 1996b; Jacober et al. 1998; Kynard et al. 2000; Bradford and Gurtin 2000
Preference curves	14	*Design I*: Baltz et al. 1991; Bozek and Rahel 1991; Beecher et al. 1993, 1995. 2002; Nack et al. 1993; Barrett and Maughan 1994; Hayes and Jowett 1994; Freeman et al. 1997; Maki-Petays et al. 1997, 1999, 2002; Guay et al. 2000
Chi-square goodness-of-fit test	14	*Design I*: Lobb and Orth 1991; Neilsen 1992; Rincon and Lobon-Cervia 1993; Roper et al. 1994; Nakamoto 1994; Shuler et al. 1994; Whalen et al. 1999; Baxter and Hauer 2000; Muhlfeld et al. 2001 *Design II*: Swanberg 1997; Jacober et al. 1998; Snedden et al. 1999; Quist et al. 1999; Bradford and Gurtin 2000
Log-likelihood chi-square test	4	*Design II*: Clapp et al. 1993; Young 1996; Quinn and Kwak 2000; Knights et al. 2002
Continuous data		
Logistic regression	10	*Design I*: Hayes and Jowett 1994; Walters and Wilson 1996; Leftwich et al. 1997; Monzyk et al.1997; Childs et al. 1998; Knapp and Preisler 1999; Geist et al. 2000; Welsh et al. 2001; Bilkovic et al. 2002 *Design II*: Paukert and Willis 2002
Linear regression	7	*Design I*: Fausch and Northcote 1992; McMahon and Holtby 1992; Cheasson et al. 1997; Irwin et al. 1997; Miranda and Pugh 1997; Baxter and Hauer 2000; Pess et al. 2002 *Design II*: Brown and MacKay 1995
Mann-Whitney *U*-test	9	*Design I*: Leis and Fox 1996; Knapp and Vredenburg 1996; Blanchfield and Ridgeway1997; Knapp and and Prieslie 1999; Baxter and Hauer 2000 *Design II*: Brown and MacKay 1995; Swanburg 1997; Young 1996; Beasley and Hightower 2000
t-test	2	*Design II*: Mathews 1996a, 1996b

Table 1. Continued.

Analytical approach	Number of studies	References
Friedman's randomized blocks	1	*Design II*: Zigler et al. 1999
Randomized blocks without ranks	1	*Design II*: Beyers and Carlson 1993
General linear model	1	*Design II*: Essington and Kitchell 1999
		Food Selection
Categorical data		
Indices of selection	9	Rondolf et al. 1990; Angradi and Griffith 1990; Schael et al. 1991; Goshorn and Epifanio 1991; Nalsji et al. 1991; Neilson 1992; Dahl-Hanson et al. 1994; Limburg et al. 1997; Van Snik Gray et al. 1997
Continuous data		
Kolmogorov-Smirnov two-sample test	2	Poe et al. 1991; Wilhelm et al. 1999
Correlation analysis	1	Elrod and Gorman 1991