

DIRECT AND INDIRECT ESTIMATES OF BLACK CRAPPIE SIZE SLECTIVITY TO
OTTER TRAWLS

By

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To my grandfather “Ace” who instilled in me at a young age a passion for fish.

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Abstract of Thesis Presented to the Graduate School
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I estimated size selectivity of bottom trawl sampling for black crappie *Pomoxis nigromaculatus* utilizing direct and indirect approaches. I used capture-recapture methods to directly measure the effects of fish size on catchability (q , the fraction of a fish stock collected with a given unit of fishing effort) at Lake Jeffords, Florida. Estimates of q were made for different length-groups roughly resembling age-classes 0 to 2 and fish 3+ (90-119, 120-149, 150-179, 180+ mm) by marking a subpopulation collected using three gear types (bottom trawls, hoopnets, and electrofishing). Recapture sampling with otter trawls occurred two weeks after marking events ended, allowing a direct estimate of q from recaptures of tagged fish from each gear and size class. Indirect estimates of selectivity were obtained with a population model applied to long-term data at four Florida lakes. I constructed age-structured models for each lake that predicted annual catches-at-age as a function of measured growth rates, a time series of recruitment anomalies, assumed survival rates, and unknown age/size selectivities. Selectivity parameters were estimated by fitting model predicted catches-at-age to a time series of bottom trawl catch-at-age using maximum likelihood. Direct measures of selectivity indicated catchability was highest for the 90-119 length-group and lowest for fish greater than or equal to 180 mm, with q declining by a factor of 2 or 3 for large fish relative to small fish. Model

simulations from the age-structured indirect approach revealed dome-shaped selectivity patterns with relative selectivities peaking at age-1 for three of four lakes. Lake Johns was the only exception where age-0 fish was the most efficiently captured age-group when survival was low. Overall model trends indicated greater selectivity of younger fish (age-0 and age-1) to the gear followed by decreasing relative selectivity to older age-classes (age-2+). Trawl selectivity patterns suggested that otter trawls would be best for monitoring the abundance of small black crappie. My results indicate that adult black crappie will likely be underrepresented in bottom trawl samples, which would influence age structure and growth rate estimates and the effectiveness of this gear as an assessment tool for tracking adult crappie populations.

CHAPTER 1 INTRODUCTION

Effective management of fishery resources is dependent on the quality of information available for decisions. To develop optimal management strategies, biologists must be confident that sampling reliably tracks population metrics. These strategies are often reliant on precise estimates of some metric of population size and its corresponding level of production (biomass/numbers). Gear selectivity can influence precision and accuracy of these measures (Hilborn and Walters 1992). Samples collected from many fish populations with a variety of gears often don't accurately describe the true age and size structure of the target population. Therefore, obtaining an abundance index that reflects the actual age/size composition of a population allows managers to monitor population trends such as recruitment, growth, and mortality and evaluate population responses to management policies (e.g., size limits) (Hilborn and Walters 1992).

When evaluating gear types, an important distinction between gear selectivity and gear efficiency must be delineated. Gear selectivity is defined as the composition of a sample relative to the true population metric (e.g. size, age, growth rate), and relative selectivity refers to the effectiveness of a sampling gear to capture a particular size or species of fish relative to its efficiency at capture of other sizes or species (Hubert 1996). In contrast, gear efficiency describes the magnitude of effort required to catch adequate sample sizes.

Gear selectivity patterns are commonly attributed to intrinsic factors like fish size (Beamesderfer and Rieman 1988, Myers and Hoenig 1997, Wakefield et al. 2007), fish density (McInerney and Cross 2000, Rogers et al. 2003), species (Laarman and Ryckman 1982, Sammons et al. 2002), sex (Jagiello 1999), behavioral patterns (Reynolds 1996, Jagiello 1999), and habitat preferences (Jacobson et al. 2001) as well as extrinsic factors such as seasonal variation (Pope

and Willis 1996), environmental conditions or characteristics (Hayes et al. 1996; McNerny and Cross 2000), diel variation (Paragamian 1989, Dumont and Dennis 1997), gear construction (O'Neil and Kynoch 1996, Lok et al. 1997, Farmer et al. 1998), gear type (Kraft and Johnson 1992, Jackson and Noble 1995, Otway et al. 1996), and sampling crew expertise.

Estimates of gear selectivity are important for fish stock assessment. Estimates of selectivity allow managers to assess population composition based on samples which may not represent the true population, and estimates of selectivity provide information on aspects of the population which is not readily observable. Adjusting for selectivity allows managers to obtain a more accurate abundance index for the age and size structure of a stock because many samples do not adequately represent the true population age or size structure. This enhances the ability of managers to draw inferences about stock trends like recruitment, growth, and mortality (Hilborn and Walters 1992).

Gear selectivities are commonly used to determine the effects of fishing on the size and age composition of a fishery and are commonly used in assessment models to link size/age structure of catch data to the size/age structure of the fish population (Walters and Martell 2004; Taylor et al. 2005). Such models are required to predict effects of different harvest rates, calculate biological reference points like spawning potential ratio (SPR), and determining appropriate levels of sustainable yield for a fishery (Maunder 2002). Thus, quantifying gear selectivity allows biologists to adjust abundance indices to represent the true size/age composition which guides future management actions.

Measurements of the selective properties of fishing gears are often made utilizing direct and indirect methods (Pollock et al. 1990; Walters and Martell 2004). Direct methods involve comparing catch composition against a known population structure. The most direct method for

estimating selectivity is a mark recapture experiment creating a known population, then calculating the proportion of fish caught by the gear in a given length category from the marked subpopulation (Hamley and Regier 1973; Myers and Hoenig 1997; McInerney and Cross 2006). Accurate estimation of selectivity using capture-recapture methods requires several assumptions including: (1) the population of interest is closed to additions and deletions. That is, recruitment, natural mortality, immigration, and emigration must be minimal, (2) tags are not lost or go undetected, and (3) equal capture probability (i.e. no capture heterogeneity and/or trap response) (Pollock et al. 1990). Unlike direct methods, indirect measures of selectivity require no prior knowledge about the age composition of a population. If catch-at-age data from the commercial or recreational sectors are available, age structured population models like virtual population analysis (VPA) can estimate the age/size selective properties of the fishing gear used. Other approaches incorporate the catch rates of various sizes of fish from different gear types and/or mesh size to compare relative gear selectivity between gears, but such studies do not identify the true selectivity of either gear (e.g., Boxrucker and Plosky 1989; Miranda et al. 1992; Millar and Holst 1997).

Indirect or relative measures of abundance such as catch per unit effort (CPUE) are commonly used by managers to assess and analyze trends in fish population abundance. In order for CPUE to directly index population abundance, the relationship between catch rate and abundance must be:

$$\frac{C}{f} = q * \frac{N}{A} \tag{1}$$

where C = catch, f = fishing effort, q = catchability coefficient (the fraction of population removed per unit of effort), N = fish abundance and A = area occupied by stock (Ricker 1975).

This equation infers a linear relationship between CPUE and abundance with a constant slope q , which is often not the case.

Catch per effort is a function of two factors: catchability and fish density (Hilborn and Walters 1992; Arreguin-Sanchez 1996). Therefore, variability in q causes variability in CPUE that is not related to population size, so catch statistics should be adjusted to account for variation in catchability. Because catchability is a function of selectivity, it is an important parameter when using CPUE to index abundance. Furthermore, when catchability coefficients are apportioned by age/size classes, the estimated coefficients are actual age/size gear selectivity estimates.

Like selectivity, catchability differs with a wide range of factors including fish age (Pierce and Tomcko 2003), fish size (Bayley and Austen 2002; McNerny and Cross 2006), species (Bayley and Austen 2002; Schoenebeck and Hansen 2005), fish density (Peterman and Steer 1981; Rogers et al. 2003), sample gear type (Hansen et al. 2000; Pierce and Tomcko 2003), environmental conditions during sampling (Bayley and Austen 2002), and sampling season (Schoenebeck and Hansen 2005; McNerny and Cross 2006). Nielson (1983) found catchability from otter trawls to be similar across age-classes of adult yellow perch. Pierce and Tomcko (2003) showed q of northern pike to vary with age in gill-nets. McNerny and Cross (2006) quantified the effects of size, season, and density of black crappie on trap-net catchability. They found q increased with fish size, and catchability was higher in spring than fall. Catchability also varied with density as both increased and decreased values of catchability were observed for different length-groups and sampling periods. Bayley and Austen (2002) provided a comprehensive evaluation of electrofishing q estimates for different fish species, sizes, and seasons under variable environmental conditions. Overall, knowledge of q can allow managers

to adjust abundance indices and estimate absolute abundances, estimate gear selectivity patterns, identify seasonal and/or environmental biases associated with sample gears, and aid in the selection of appropriate gears to maximize management objectives.

Black crappie support one of the most popular sport fisheries in North America often ranking first or second among angler preference, but can be difficult to manage. Sampling crappies to accurately describe rate functions (such as growth and mortality), abundance and size structure is often demanding requiring much effort. Indexing black crappie abundance and size structure is challenging due to differences in gear performance and selectivity patterns. In the Midwest, trap nets have been useful in collecting large samples of crappie of all sizes (Gablehouse 1984; Colvin and Vasey 1986; Boxrucker and Ploskey 1989), but true gear selectivity has rarely been measured (but see McInerny and Cross 2006). Conversely, trap nets in some southeastern systems collected young fish but few adults (Sammons and Bettoli 1998; Maceina et al. 1998). Miranda and Dorr (2000) quantified the size selective effects of crappie angling in five southeastern systems and reported dome-shaped selectivity for crappie vulnerable to angling (size range: 20.0 to 39.8 cm) with smaller and larger sized crappie less susceptible than intermediate sizes indicating differences in catchability and thus, exploitation.

Trap net efficiency and relative selectivity has been evaluated and compared to other gears in numerous studies to determine which methods of capture are most effective (McInerny 1989; Boxrucker and Ploskey 1989; Miranda et al. 1992; St. John and Black 2004). McInerny (1989) found trap nets were the most effective and cost-efficient gear deployed for sampling black crappie populations at Lake Wylie, North Carolina. Miranda et al. (1992) reported a higher catch per effort with trap nets compared to electrofishing in the spring and rotenone sampling in the summer for four Mississippi waters. Boxrucker and Ploskey (1989) revealed greater sampling

efficiency and less variation in catch per effort with trap nets when compared to electrofishing and gillnetting. Thus, trap nets have provided useful data in some cases, but the selectivity of trap nets relative to the population size/age has seldom been measured.

Otter trawls have received far less attention than other capture methods to index crappie abundance. In Florida waters, otter trawls have proven to be successful at capturing black crappies (Schramm et al. 1985; Allen et al. 1999; Pine 2000). Allen et al. (1999) compared the relative efficiency of trap nets versus otter trawls for sampling black crappie in two Florida lakes and reported that trawl sampling was superior to trap nets based on the size range of fish collected, accuracy of abundance estimates, required sampling effort, and expenditures associated with gear. Pine (2000) compared the relative selectivity of two different sized bottom trawls and found a smaller trawl was more effective at collecting juvenile black crappie than a larger trawl. Despite the importance of black crappie in Florida and the popularity of bottom trawls for sampling crappie populations, trawl selectivity of black crappie relative to the population has not been measured. Thus, in order for biologists to utilize trawl catch data for management it is important to understand the selective properties of the gear relative to the population. This will enhance the ability of managers to use trawl CPUE as an index of abundance as well as length and age frequency information to describe the size/age structure of black crappie populations. My objectives were to (1) estimate size-specific catchability (q) of black crappie collected with otter trawls (2) estimate relative age/size-specific selectivity of bottom trawl gears and (3) use those selectivity patterns to evaluate the utility of otter trawls as an assessment gear for black crappie for Florida lakes.

CHAPTER 2 METHODS

Direct Measure of Selectivity

Capture-recapture sampling took place at Lake Jeffords, Florida during January 2007.

Lake Jeffords is a 65 hectare, mesotrophic (Pine 2000) system located in Alachua County, North Central Florida (Figure 1). I selected Jeffords because I felt I could adequately sample the entire lake (i.e. sample all available habitat types) and create a large enough marked subpopulation to obtain reliable catchability estimates.

Mark-recapture methods were used to create a tagged population using three gear types. Marking took place over a 10 day period in January 2007, with electrofishing gear sampled on day 1, otter trawls sampled on days 1, 2, and 3, and hoopnets sampled on days 7 - 10. I sampled with three gears during the marking event to ensure all available habitat types of the lake were sampled. The recapture event took place over a two day period with bottom trawls two weeks after the first marking day. I only used bottom trawls during the recapture period, which allowed estimation of trawl size selectivity based on my known tagged population. The perimeter of the lake was electrofished at both events to ensure fish had not moved into the shallow littoral zone where it is not possible to effectively trawl. Captured fish from all trawls were divided into subgroups by length. This division allowed estimation of q by size, providing a measure of actual trawl size selectivity. The length-groups (mm) roughly resembled ages 0 (90-119), 1 (120-149), 2 (150-179) and adult fish three or older (180+). Abundance estimates were obtained using a Lincoln-Peterson estimator (due to closed system and 2-stage mark-capture sampling event) and the proportions of marked fish were calculated as the number of fish caught in the recapture divided by the abundance estimate. All black crappie captured in the field during marking were measured for total length (TL) to nearest (mm) and pelvic fin clipped. Since only

two weeks passed from mark to recapture events and fish were fin clipped instead of using conventional tag types like a T-bar tag, I assumed tag loss to be negligible. All black crappie captured during the recapture were measured for total length to nearest (mm) and checked for fin clips.

Bottom trawls were pulled from a 7-m boat powered with a 70 hp outboard in all areas of the lake except in the shallow littoral zone to avoid fouling by vegetation. Effort was constant throughout the study at three minutes per trawl. The trawl net consisted of a 4.88-m long body and 4.6-m mouth and the body is constructed with 38.1 mm stretch mesh and 31.8 mm stretch mesh in the cod end (Allen et al. 1999). Under tow, the mouth of the trawl is spread open with floats (25 x 50 mm) that are secured to the headrope of the trawl mouth. The sweep, or chain line, was attached to the footrope of the net. Wooden doors (38.1 x 76.2 cm) were secured to 146 cm leglines and a 15.3-m trawl bridle. The weighted doors served to open the trawl mouth and allowed the net to sample near the bottom.

Modified hoop nets were deployed in the middle of the lake at various sites. Hoop nets consisted of four similar-sized fiber-glass hoops either 0.9, 1.2 or 1.5m in diameter and covered with 5.1cm stretch nylon mesh webbing. A 23-m lead was used to connect two nets, which would direct fish toward a hoop net as they traveled along the lead. All hoop nets were set during the day, fished for 48 hours, and retrieved. Hoop nets were only used for capture sampling event.

Electrofishing was conducted with a Smith-Root model SR18 electrofisher, equipped with a Smith-Root 9.0 GPP pulsator powered by a 9,000 Watt generator. Approximately 7 amps of DC current were produced at 120 pulses per second. The entire shoreline perimeter was sampled (as described above) with an experienced crew of one netter and one boat operator.

I estimated tagging mortality, defined as mortality from capture, handling, and tagging for each size-group to adjust the size of our marked population available for recapture. A sub-sample of marked fish were held in aerated bait tanks and placed in holding pens as replicates ($n = 8$) for 24 hours to estimate associated tagging mortality for different length-groups. Holding pens were constructed out of pvc pipe which consisted of a rectangular frame that measured 3.0 m length by 1.25 m width. The body of the holding nets consisted of 19.3 mm stretch mesh webbing that extended to a depth of 1.1 m. The observed mortality rates for each size-group and holding pen were randomly re-sampled with replacement using a bootstrap to create 1,000 Monte Carlo estimates (Haddon 2001). The 95% confidence intervals were calculated at the 2.5 and 97.5 percentiles using the means of the resample from the bootstrap.

I used maximum likelihood methods to estimate how q varied with fish size. The Poisson log likelihood function was appropriate and indicated as

$$\ln L(O_i | q) = -\sum (P_i) + \sum (O_i) * \ln(P_i) \quad (2)$$

where $P_i =$ (number available for recapture in size-group $i * q * \text{effort}$) and $O_i =$ (number of observed recaptures in size-group i). Catchability for each length-group was estimated by maximizing the negative likelihood function (i.e. minimize the differences between the observed and expected recaptures). Parameters for the model included survival from marking ($S = 1 - \text{observed tagging mortality}$), number available for recapture = (number marked * S), and q , the fraction of population caught per unit of effort.

To describe the uncertainty in q estimates, I constructed likelihood profiles for each length-group. These profiles were probability distributions (i.e. p-values) for the parameters. The 95% confidence intervals for each parameter were calculated using Wilk's likelihood ratio test statistic (Pawitan 2001) equal to

$$W = 2 * \ln\left(\frac{L(\hat{\varphi})}{L(\varphi)}\right) \quad (3)$$

where W = Wilk's statistic, $L(\hat{\varphi})$ = log likelihood at MLE, and $L(\varphi)$ = log likelihood at some φ value less than the maximum likelihood estimate (MLE). Wilk's statistic conforms to a Chi-square distribution with one degree of freedom (Pawitan 2001).

Indirect Measure of Selectivity

Black crappie populations in Florida lakes have been sampled with otter trawls over the last two to three decades. I used a long-term database from four lakes to estimate the size/age selectivity of bottom trawls using an age-structured population modeling approach. In this context, selectivity was defined as differences in relative fish susceptibility due to size/age. The model was used to estimate selectivity at age by comparing observed and model-predicted catches-at-age using maximum likelihood estimation.

Annual bottom trawl sample data were obtained from lakes Griffin, Johns, Lochloosa, and Okeechobee (Figure 2). The length of the data time series varied among lakes and ranged from five years for Lake Johns (2002-2006) to 20 years at Lake Okeechobee (1987-2006). All lakes exceed 1,500 ha with mean depths ranging from 1.8 m to 2.8 m and are classified as eutrophic or hypereutrophic (Florida Lakewatch 1999, 2001; Forsberg and Ryding 1980) (Table 1).

Black crappie populations were sampled using a combination of fixed and/or random sites. Lakes Lochloosa and Johns were divided into 250m² grids using ARC GIS software with buffers built in to avoid sampling in the vegetated littoral zone. Vegetation fouls the gear, reduces gear performance, and does not allow an accurate assessment of gear utility. At Lake Lochloosa, fixed and random sites were used throughout, whereas Lake Johns data were obtained from randomly generated fixed sites until years 2005 and 2006 where a combination of six fixed and six random sites were used. At Lake Griffin, 25 to 68 trawls were pulled based on a similar but

slightly different SRS design (fixed sites to 2002 and random sites from 2003). One to 20 trawls were pulled at Lake Okeechobee on the north end of the lake from 0.8 to 2.4 km offshore between Taylor Creek Lock (S-193) and Nubbin Slough Spillway (S-191) until 500 black crappies were captured. In 2005, due to a large drop in numbers likely attributed to the 2004 hurricane effects on the lake, the sampling focus changed from minimum numbers to minimum effort (~150 minutes). In lakes where a combination of fixed/random sites were used in a given year (Johns, Lochloosa) I tested for differences in mean CPUE and size structure to determine if fixed and random site samples could be pooled. Analysis of variance (ANOVA) indicated no significant site type or year*site type effects on mean CPUE for both lakes: Johns ($P = 0.48$, $P = 0.44$), Lochloosa ($P = 0.86$, $P = 0.08$). Differences in size structure by site type were evaluated using a Chi-square test and results indicated no significant differences in size structures between fixed or random sites in any year. Based on these findings, I combined fixed and random sites for the analysis.

There were some method differences among the lakes. Trawls were towed at a speed 2.0 – 2.5 m/s (1800-2000 RPM) with the exception of Lake Okeechobee where trawls were pulled at 1.0 m/s. Effort was constant throughout the study at three minutes per trawl with the exception of Lake Lochloosa where some trawls were pulled for five minutes, and Lake Okeechobee where trawls were pulled for 15 or 30 minute intervals (see Miller et al. 1990). Samples were collected during daylight hours from October – December at Lakes Griffin, Johns and Lochloosa, and in January at Lake Okeechobee. The trawl net used at Lakes Griffin, Johns, and Lochloosa was the same as used for Lake Jeffords capture-recapture sampling (described above) which I will refer to as the standard trawl net. Lake Okeechobee trawl net was similar in design and application

but was larger, having a 10.7-m headrope, 32-mm square body mesh, and 25-mm square cod end mesh.

All black crappie captured in the field were measured for total length (TL) to nearest (mm). Subsamples of five fish per one cm group were brought back to the laboratory for further analysis. However, age data were collected only every other year from 2001 to 2006 at Lake Lochloosa. At the laboratory, gender, total length (TL) to nearest (mm), total body weight (TW, g) were determined and sagittal otoliths were removed. Ages were determined in whole view by two independent readers as the number of opaque bands on sagittal otoliths. Otoliths from fish older than two years as well as any discrepancies on whole reads were sectioned along the dorsoventral plane before aging. Use of black crappie otoliths for aging in Florida has been validated by Schramm and Doerzbacher (1982).

I used an age-structured population model to estimate the relative age/size-specific selectivity of black crappie to bottom trawls at each lake. The model predicted catch-at-age as a function of von Bertalanffy growth parameters, annual relative recruitment anomalies, an arbitrary number of initial recruits, assumed instantaneous rates of total mortality ($Z_0 = e^{-Z_0} =$ survival (S_0) to age-1, $Z = e^{-Z} =$ survival (S) past age-1), and unknown age/size-specific selectivities (to be estimated). The numbers at age ($N_{a,t}$) in a given year were estimated as

$$N_{0,t} = R_t * R_o \tag{4}$$

$$N_{1,t} = N_{a-1,t-1} * S_o \tag{5}$$

$$N_{2,t} = N_{a-1,t-1} * S \tag{6}$$

where R_t are annual recruitment anomalies, R_o is the average annual recruitment numbers (arbitrary value used to scale model), S_o is survival from age 0 to age 1, and S is annual survival for age-1+ fish. Different survival rates for age-0 relative to older fish were used because of

expected lower survival for age-0 fish. Annual recruitment anomalies (R_t) for each lake and year were estimated by dividing mean catch per effort (CPUE) of age-0 crappie in year t by the median age-0 CPUE across all years. This provided an index of strong and weak year classes in the population model and was used as a basis for predicting future catches-at-age with the trawls. This model allowed prediction of the relative numbers of fish at each lake, age, and year based on the input parameters. From the numbers at age matrix, I predicted a catch-at-age matrix from a hypothesized selectivity schedule. Expected catch at age was calculated as

$$C_{a,t} = N_{a,t} * S_a \quad (7)$$

where $C_{a,t}$ is the catch at age at time t , and S_a are unknown selectivity at age parameters.

Growth parameters were estimated using the von Bertalanffy growth equation fitted to weighted mean length at age data obtained from age-length keys using the technique described by Devries and Frie (1996). The von Bertalanffy equation is

$$L_a = L_\infty * (1 - e^{(-K*(a-t_0))}) \quad (8)$$

where L_a is length at age, L_∞ represents the average asymptotic length, K is the metabolic growth coefficient, a is fish age, and t_0 is the age at zero length. A growth model was constructed for each lake by pooling annual length-age samples after determining that growth did not differ widely among years. The von Bertalanffy growth model was also used to link my age-based selectivities to length-based selectivities for each cohort.

Because fish suffer higher rates of mortality early in life than adults (Hjort 1914; Cushing 1975), my base model assumed different instantaneous rates of total mortality for these two life stanzas: $Z = 1.2$ ($S_0 = 0.30$) for survival to age-1, and $Z = 0.6$ ($S = 0.54$) for ages 1+. These rates served as a base for comparison to other simulations under varying assumptions for S_0 and S . I evaluated the sensitivity of selectivity estimates to different survival rates by estimating

selectivity parameters under different values of S_o and S . Values of S_o ranged from 0.22 to 0.37 and S ranged from 0.45 to 0.67.

Observed catch-at-age for each lake and year was estimated using age-length keys. Because age data were only collected at Lake Lochloosa every other year, we used the previous and post years age data as the basis for an age length key (e.g., 2002 age structure was estimated using 2001 and 2003 age-length subsamples), and apportioned fish to ages based on the existing length data. Observed catch-at-age for each year was standardized for sampling effort by dividing the catch-at-age by the total lake effort (trawl minutes) for that year.

I used a multinomial log likelihood function to estimate selectivity at age by minimizing the differences between observed and expected (i.e., model-predicted) proportions of catch-at-age using the Solver function in Excel. The multinomial log likelihood equation was

$$\ln L(O_{a,t} | S_a) = n \sum_a \sum_t O_{a,t} \ln(P_{a,t}) \quad (9)$$

where n is the number of years model fit to catch data, $O_{a,t}$ represents the observed proportion of catch at age a in year t , and $P_{a,t}$ is the predicted proportion of catch at age a in year t . I used a logit transformation on selectivity parameter estimates in the optimization routine to constrain selectivities between zero and one. When working with a parameter such as a probability that must be between zero and one, the logit transformation allows parameter estimates to range from $-\infty$ to ∞ . The logit transformed selectivities were calculated as

$$X' = \ln\left(\frac{S_a}{1 - S_a}\right) \quad (10)$$

where X' is the logit transformed selectivity at age. This logit transformation was used when solving for the point estimates of selectivity, as well as for the likelihood profiles (below).

Parameter uncertainty was evaluated by calculating 95% likelihood profile confidence intervals via a likelihood ratio test (Hilborn and Mangel 1997) using the likelihood profile function in Poptools for Excel (www.cse.csiro.au/poptools/). The profile function allowed me to test alternative parameter estimates for all age-specific selectivities by holding one selectivity estimate constant, then iteratively solving for the maximum likelihood estimate by varying the remaining parameters and repeating with different values until the profile was constructed. The likelihood ratio test (LRT) was expressed in terms of the differences in the deviance or twice the difference between the negative log-likelihoods (Hilborn and Mangel 1997). The deviance for each simulation was found by

$$-2 * (LnL_{rest} - LnL_{max}) \quad (11)$$

where LnL_{rest} is the likelihood value for restricted or nested model and LnL_{max} is the maximum likelihood value for full model. The likelihood ratio test is described by a Chi-square distribution with r degrees of freedom. The degrees of freedom were determined by the difference in the number of parameters estimated between the models (Hilborn and Mangel 1997). The LRT allowed comparisons of the probabilities for each selectivity estimate occurring relative to alternative parameter values (hypotheses).

CHAPTER 3 RESULTS

Direct Measure of Selectivity

The number of marked fish and size range captured varied by gear type. I marked 1,250 fish with bottom trawls (size range: 80 – 365 mm), 23 fish with hoopnets (160 – 312 mm), and 9 with electrofishing gear (123 – 318 mm). Recapture with bottom trawls netted 788 fish (88 – 304 mm), 54 of which were previously marked individuals. Based on my recapture rates and adjusting for differential tagging mortality, I marked approximately 0.065 % of the total black crappie population at Lake Jeffords. I marked 0.098 % of fish in group 90-119, 0.064 % of fish in 120-149, 0.073 % in 150-179, and 0.041 % of fish 180+.

Tagging mortality for the smaller length groups (90-119, 120-149 mm) was much higher compared to the larger groups (150-179, 180+ mm) (Figure 3). The 90-119 and 120-149 length-groups experienced high tagging mortality at 68 and 36%, respectively. The 150-179 and 180+ groups experienced much lower tagging mortality rate averaging only 12 and 1%. Overall, tagging mortality was much higher for the two smallest length-groups relative to larger fish.

The likelihood profiles for each group indicated an overall decreasing trend in q with increasing fish size (Figure 4). Results showed that the maximum likelihood estimates (MLE's) of q for the length-group 90-119 were 2 to 3 times higher than q estimates at larger sizes, assuming the calculated mean tagging mortality. The likelihood profiles revealed high uncertainty in all the estimates of q , but higher uncertainty for the 90-119 mm size-group when compared to other groups. Figure 5 shows the lower and upper 95% confidence bounds for the MLE's using mean mortality estimates.

I evaluated how uncertainty from tagging mortality estimates would influence estimates of q . The maximum likelihood estimates for q based on the lower, mean and upper tagging

mortality rates are presented in Figure 6. Based on mean tagging mortality rates, maximum likelihood estimates for length-group 90-119 were approximately twice the MLE values of groups 120-149, 150-179 and three times as high as length-group 180+. Differences in the MLE estimates based on low tagging mortality among size-groups were reduced, except for groups 90-119 and 180+ which still varied by a factor of two. In contrast, MLE estimates applying high tagging mortality exhibited large variation among length-groups where q varied by a factor greater than 2 when comparing the 90-119 group to groups 120-149, 150-179 and a factor of 4 to group 180+. Overall model trends indicated decreasing catchability to trawl gear as fish length increased, with a greater amount of uncertainty in the estimates for the smallest length group (90-119).

Indirect Measure of Selectivity

Black crappie growth varied among lakes (Figure 7). Average asymptotic length (L_{∞}) among lakes varied from 335 to 398, whereas metabolic growth coefficient (K) ranged from 0.27 to 0.42, and t_0 from -0.79 to -1.17. As expected, lakes with higher K values had lower L_{∞} values, and vice versa (Figure 7).

The general patterns observed in the catch-at-age data included higher catches of age-0 and age-1 fish relative to older age classes, as would be expected for any population. Age-0 catch rates among the lakes varied from 0.018 to 16.84 with an average of 3.24 (fish/min). Age-1 catch at age ranged from 0.016 to 10.83 with a mean of 2.12, whereas age-2 CPUE varied from 0.007 to 7.45 and averaged of 0.94 (fish/min). Catch rates for crappie 3 and older were considerably less relative to younger age-classes and ranged from 0 to 3.70 with average catch rates to 0.37 (Table 2).

Relative recruitment anomalies varied by lake and some lakes exhibited large fluctuation in recruitment while others showed little variability in recruitment strength (Figure 8). The

recruitment anomalies for Lake Griffin varied from 0.24 to 3.57 with an average value of 1.13. Lake Johns recruitment values varied from 0.85 to 1.12 with a mean relative recruitment of 0.99 indicating little variability in recruitment. Lake Lochloosa anomalies ranged from 0.14 to 2.35 with an average recruitment value of 1.04. Lake Okeechobee exhibited large fluctuations in year-class strength with recruitment values ranging from 0.01 to 5.01 with a mean of 1.50. Thus, the recruitment trends as indexed with age-0 fish catch rates suggested substantial variation in recruitment among years at each lake.

My age structured model estimated dome-shaped selectivity with peak values for black crappie in bottom trawls at age-1. In general, age-0 and age-1 fish were more susceptible to trawl gears than older age-classes (ages-2+). Model simulations for the base model ($Z_o = 1.2 = S_o = 0.30, Z = 0.6 = S = 0.55$) revealed peak selectivity at age-1 for all lakes (Figure 9). The average selectivity schedule for Lakes Griffin, John, and Lochloosa sampled with the standard bottom trawl gear also indicated peak selectivity at age-1 (Figure 10).

Varying assumptions for instantaneous rates of mortality (i.e. survival) influenced the selectivity parameter estimates. When survival to age-1 increased (lower Z_o) greater numbers of older fish were available for capture decreasing the corresponding proportion of age-0 fish in the catch, thus increasing selectivity estimates for age-0 fish (Figure 11). Under this scenario, all selectivity schedules peaked at age-1 as before, but selectivity estimates for age-0 fish increased. Lake Johns was the only exception which exhibited peak selectivity at age-0 declining with age if survival to age-1 increased (Figure 11). Conversely, when survival to age-1 decreased (higher Z_o) fewer numbers of older age-classes were available for capture, decreasing their proportion in the catch. The corresponding proportion of age-0 fish in the catch increased resulting in lower age-0 selectivity estimates. When survival past age-1 increased (lower Z), greater numbers of 2+

age-class fish were available for capture which resulted in increased proportions of older fish in the catch. These increased proportions of older age-classes represented in the catch resulted in decreased selectivity estimates for those ages. If survival past age-1 decreased (higher Z) fewer numbers of 2+ age-class fish became available for capture. Under this scenario, decreased proportions of older fish resulted in increased selectivity estimates. Overall, the selectivity estimates for the older age-classes were more sensitive to changes in survival compared with age-0 and age-1 estimates (Figure 11). For example, Lake Okeechobee results indicated the selectivity estimates for the older age-classes could vary by a factor of 2 or 3 from the base model estimates. Nevertheless, changes in assumed survival rates did not change the overall pattern of dome-shaped selectivity for bottom trawls (Figure 11).

The uncertainty in the age-specific selectivity estimates are described from probability profiles (similar to p-values) for each lake in Figures 12 - 15. Most age-specific selectivity profiles indicated wide probability bands with potential selectivity estimates ranging from 0 to 1 for most lakes. Lake Okeechobee estimates exhibited tighter intervals relative to other lake selectivity estimates. This is likely attributed to a longer time-series of data (model fit to 10 years), whereas other lakes had shorter data time-series resulting in wider probability bands. Age-1 selectivity exhibited tighter intervals (on average from 0.70 to 1) than all other age-groups.

Table 3-1. Summary of Lake characteristics for study locations, including county of location, surface area in hectares (ha), Chlorophyll-a , concentration measured in (mg/L), trophic status, and years sampled. Trophic state based on Forsberg and Ryding (1980), Florida Lakewatch Data (1999, 2001), Bachman et al. (1996)

Lake	County	Surface Area (ha)	Chlorophyll-a (µg/L)	Trophic State	Sample years
Griffin	Lake	6,679	159	Hypereutrophic	1999-2006
Johns	Orange	1,676	13	Eutrophic	2002-2006
Lochloosa	Alachua	2,631	101	Hypereutrophic	2000-2006
Okeechobee	Glades	173,000	30	Eutrophic	1987-2006

Table 3-2. Summary of CPUE-at-age (fish/min) data showing the mean, minimum, and maximum values for each age and lake and combined across lakes.

Lake		Age-0	Age-1	Age-2	Age-3	Age-4	Age-5
Griffin	Mean	5.32	2.04	0.43	0.09	0.03	0.01
	Min	1.15	0.17	0.01	0.01	0.00	0.00
	Max	16.84	4.41	0.66	0.19	0.08	0.04
Johns	Mean	3.78	1.29	0.23	0.06	0.01	-
	Min	3.25	0.26	0.04	0.02	0.00	-
	Max	4.22	2.14	0.47	0.14	0.04	-
Lochloosa	Mean	3.85	1.63	0.46	0.06	0.01	0.01
	Min	1.23	0.43	0.19	0.02	0.00	0.00
	Max	9.31	4.46	0.84	0.12	0.04	0.02
Okeechobee	Mean	2.06	2.53	1.48	0.67	0.22	0.13
	Min	0.02	0.02	0.06	0.02	0.01	0.00
	Max	7.65	10.83	7.45	3.70	1.31	1.41
Combined	Mean	3.24	2.12	0.94	0.37	0.12	0.08
	Min	0.02	0.02	0.01	0.00	0.00	0.00
	Max	16.84	10.83	7.45	3.70	1.31	1.41

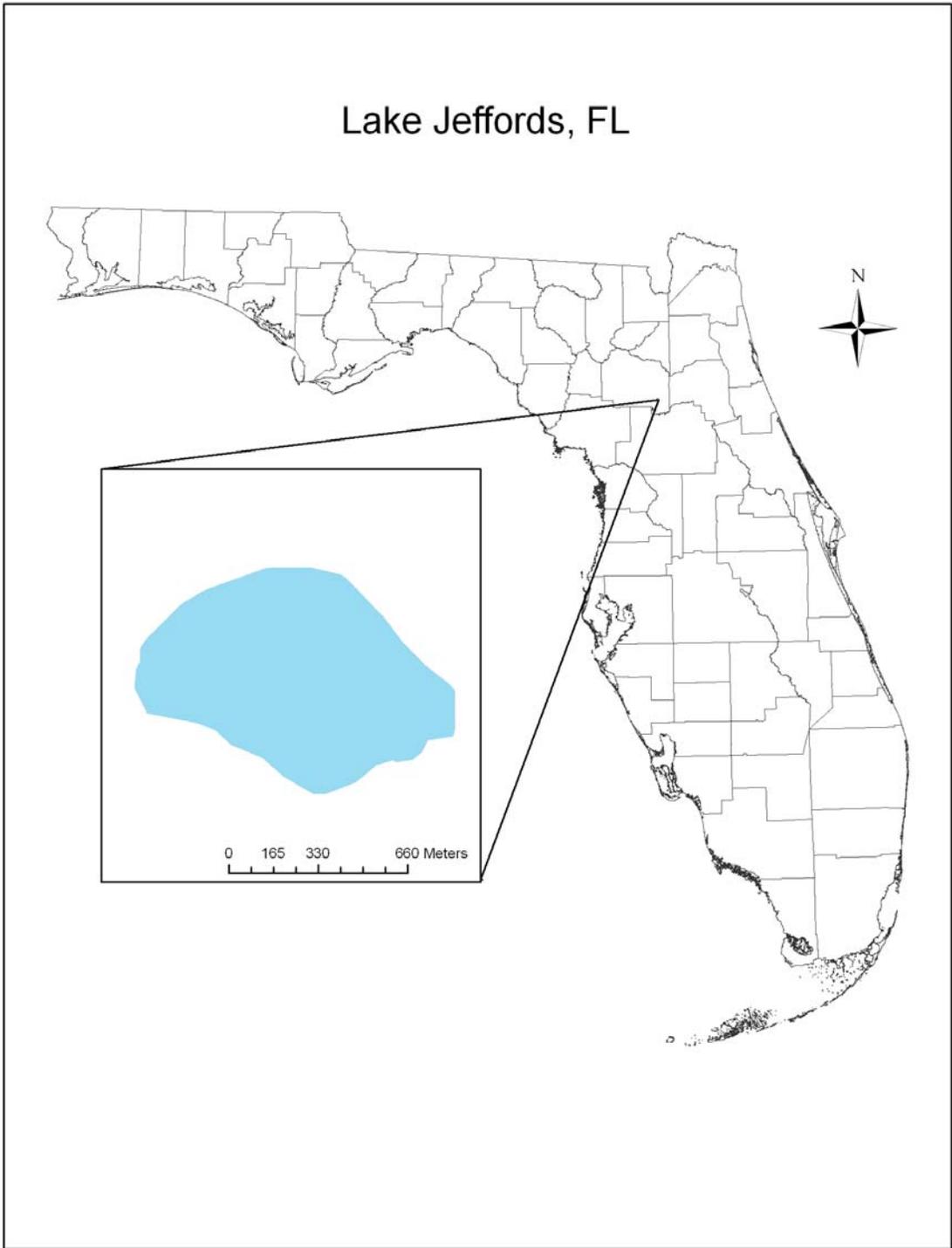


Figure 3-1. Lake Jeffords located in Alachua County, North Central Florida

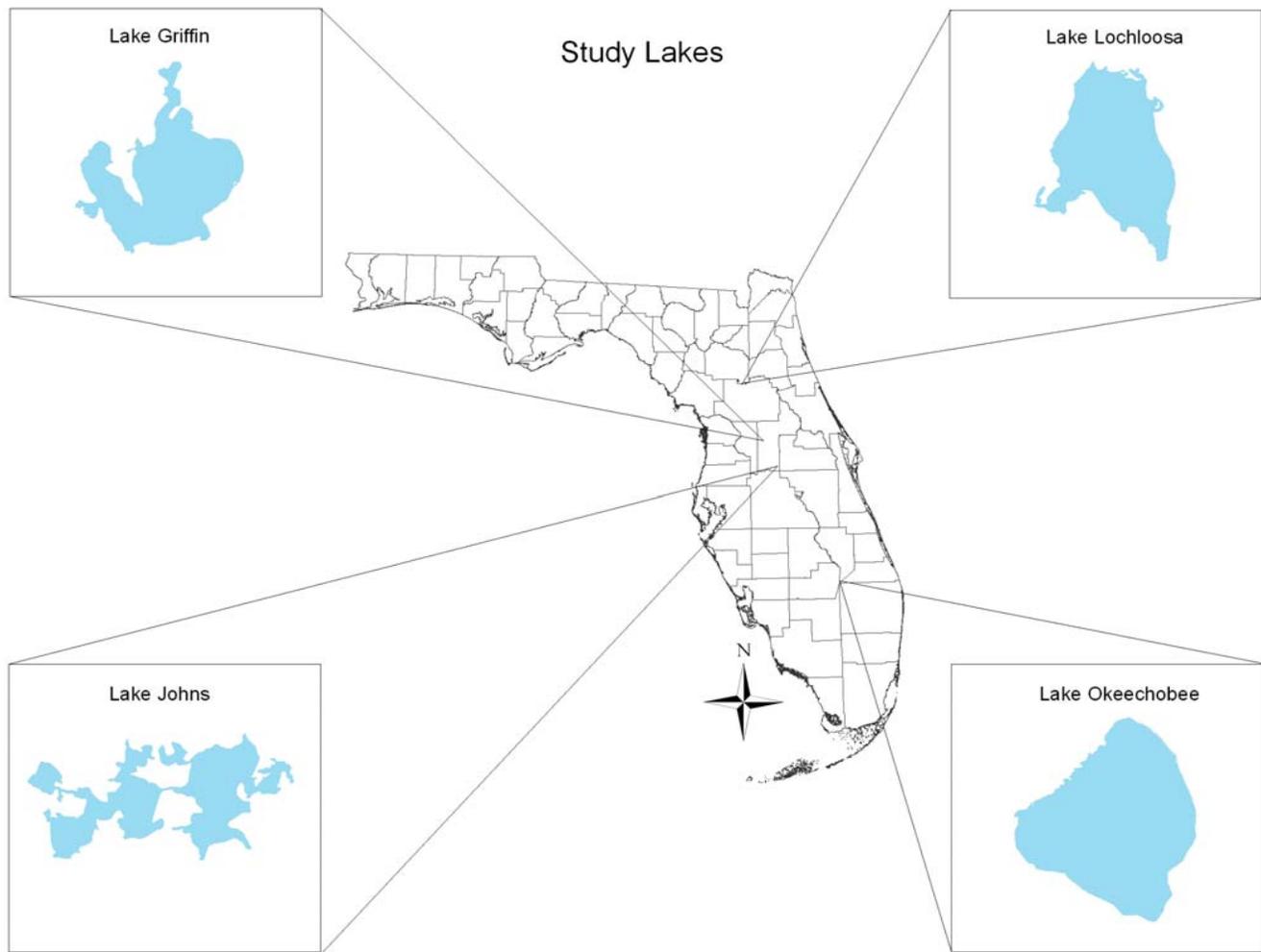


Figure 3-2. Geographic location of study lakes used for indirect measure of trawl size selectivity

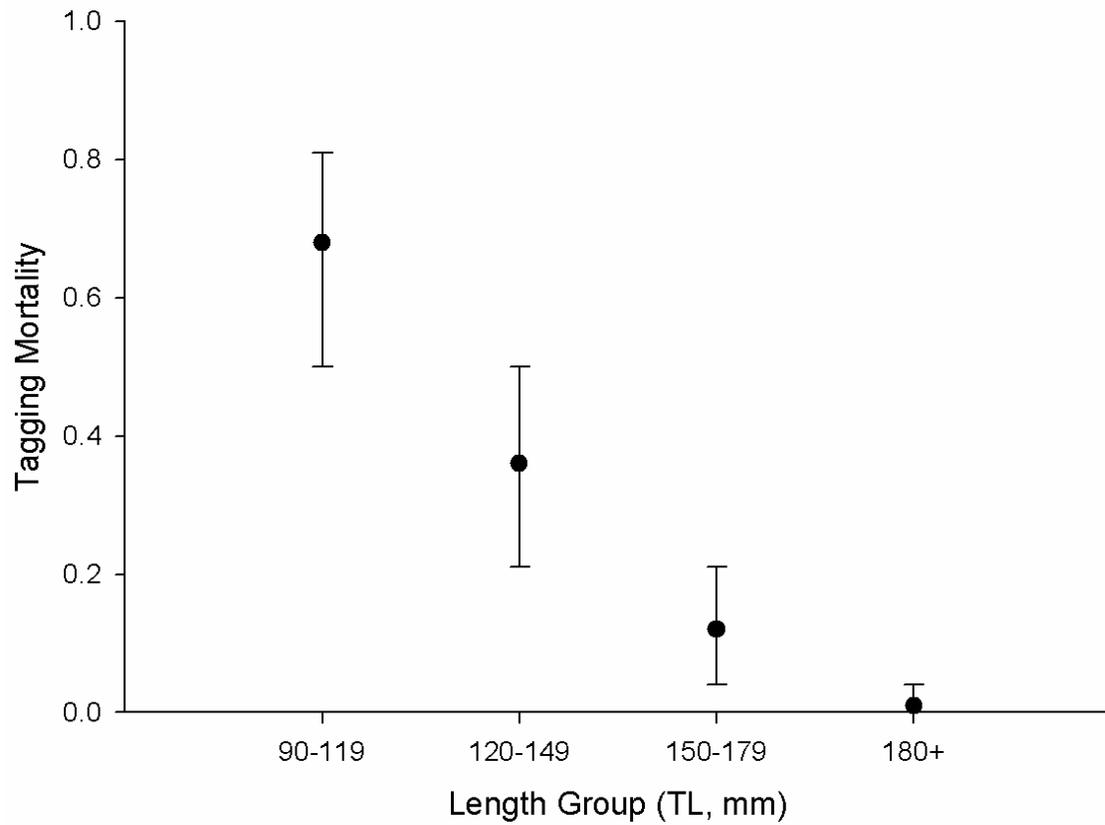


Figure 3-3. Bootstrap estimates of mean tagging mortality. Error bars represent 95% confidence intervals.

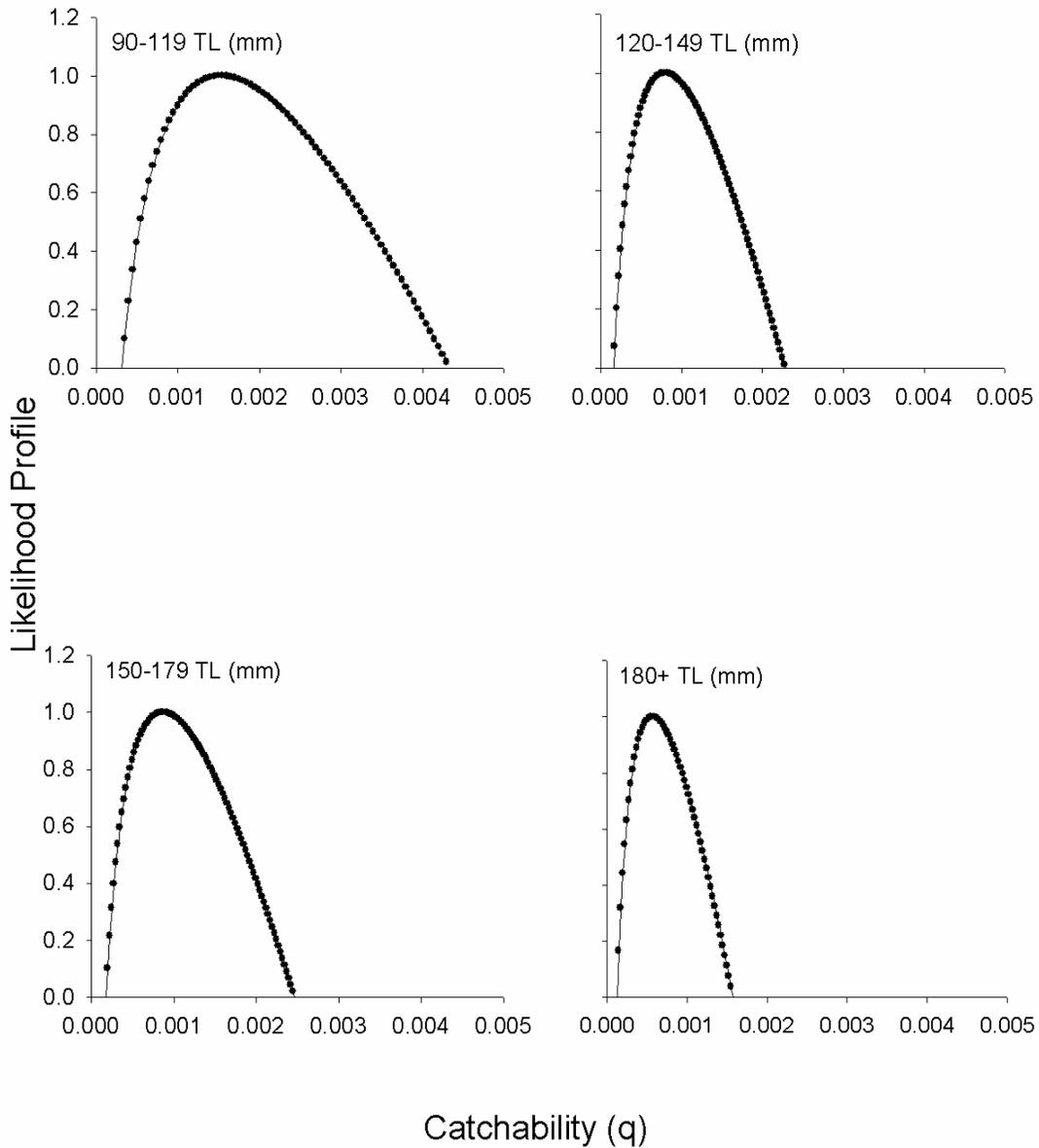


Figure 3-4. Likelihood profiles for q by length-group using mean tagging mortality rates. Maximum likelihood estimates (MLE's) represented at peak of each curve.

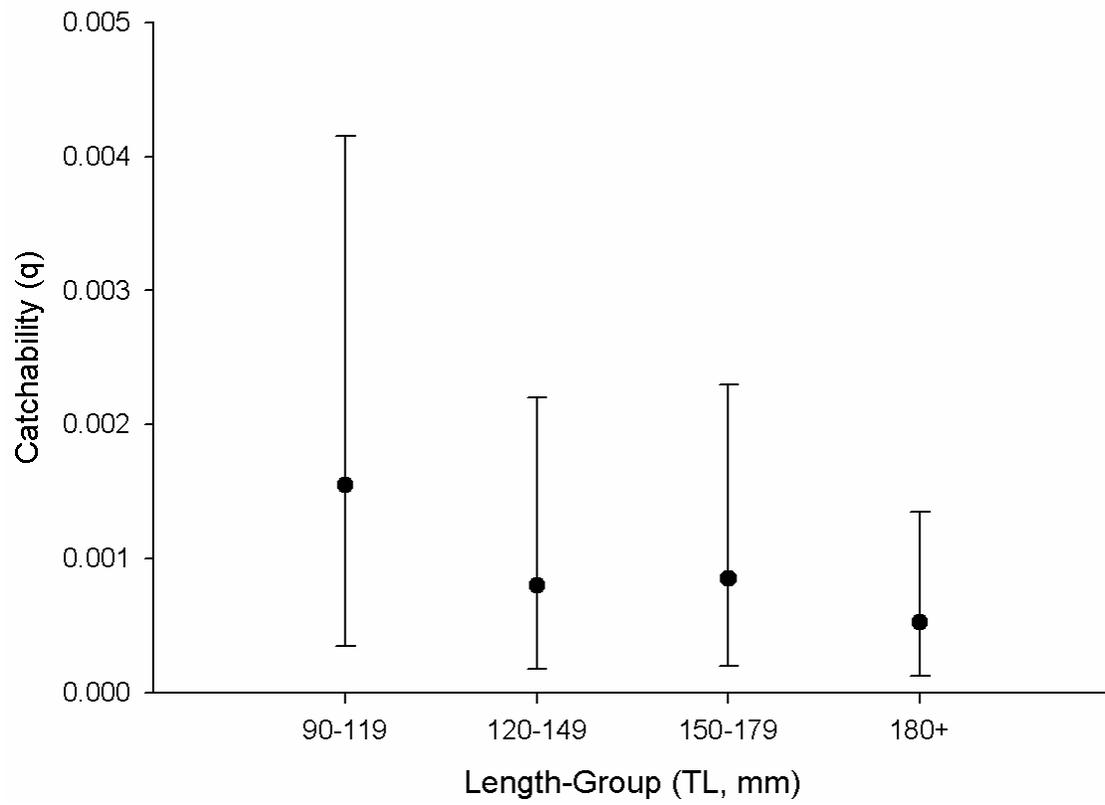


Figure 3-5. Maximum likelihood estimates of q by length-group and associated 95% confidence intervals using mean mortality rates.

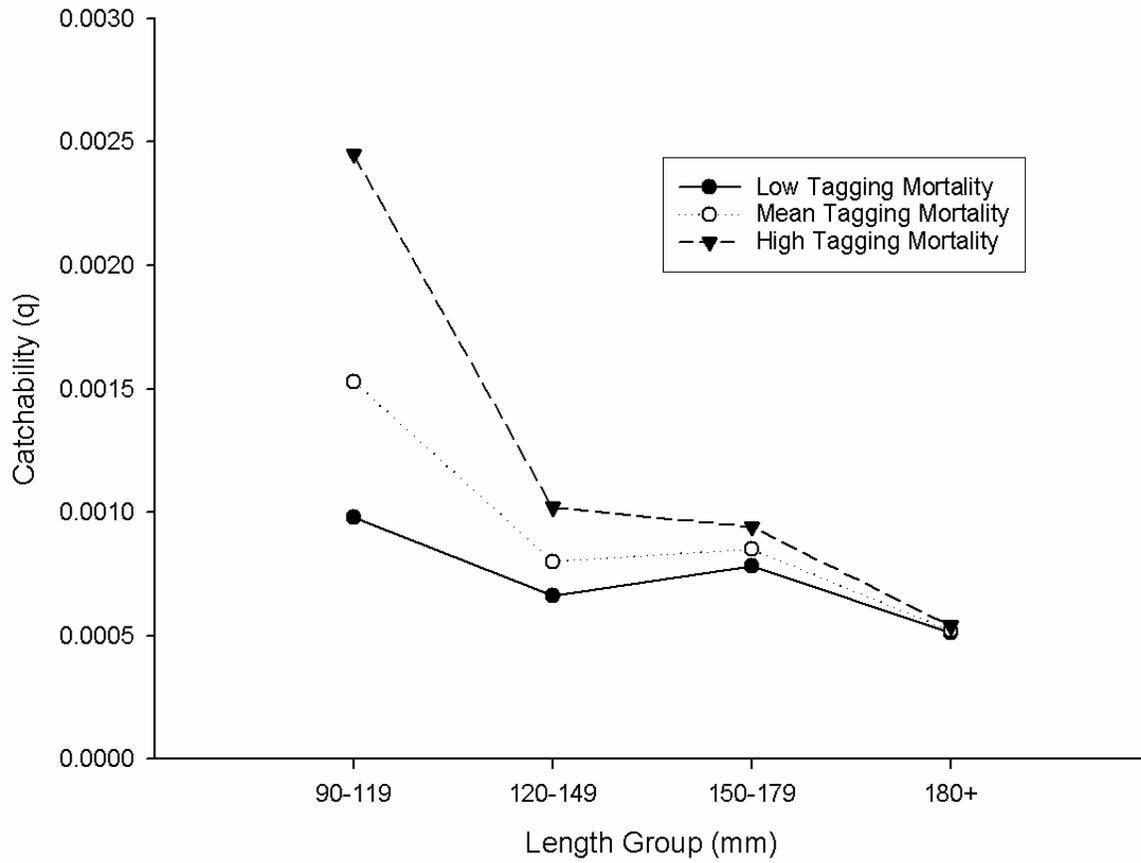


Figure 3-6. Maximum likelihood estimates for q calculated from the lower, mean, and upper tagging mortality rates.

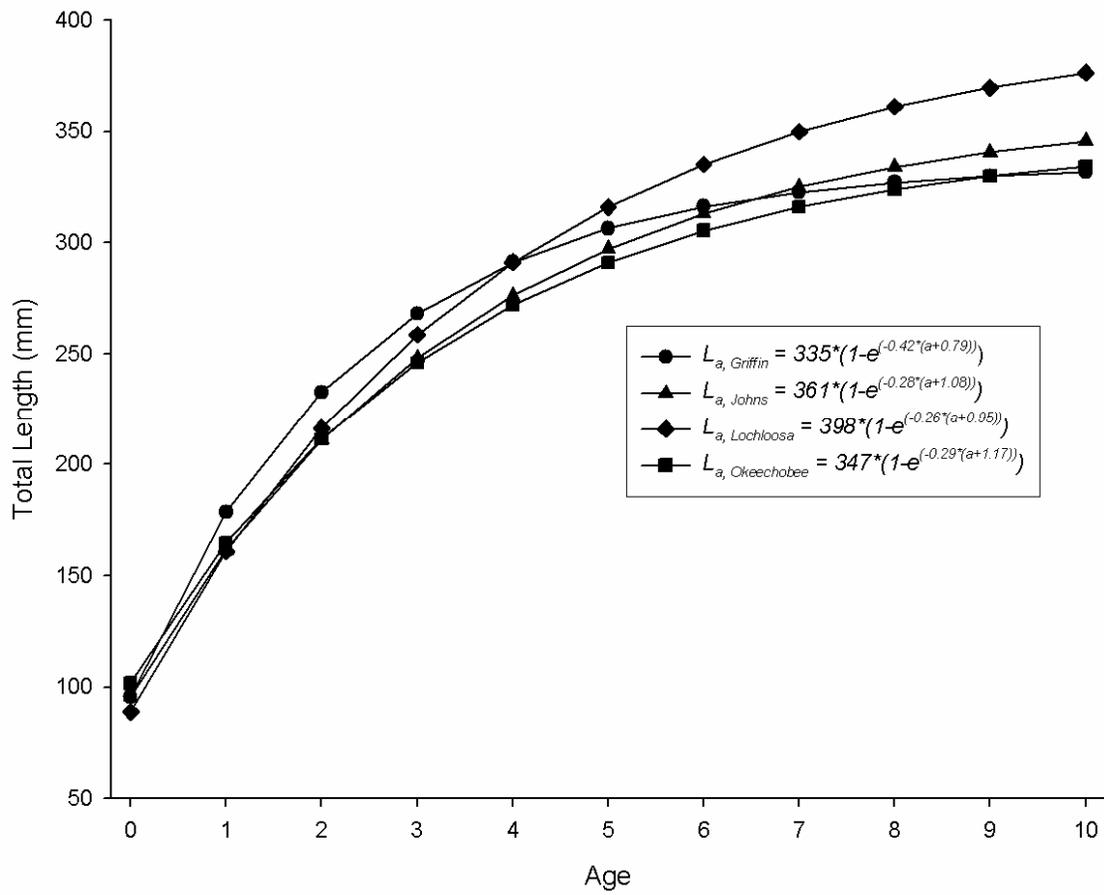


Figure 3-7. Predicted mean length at age for each lake. The least-squares equations are shown.

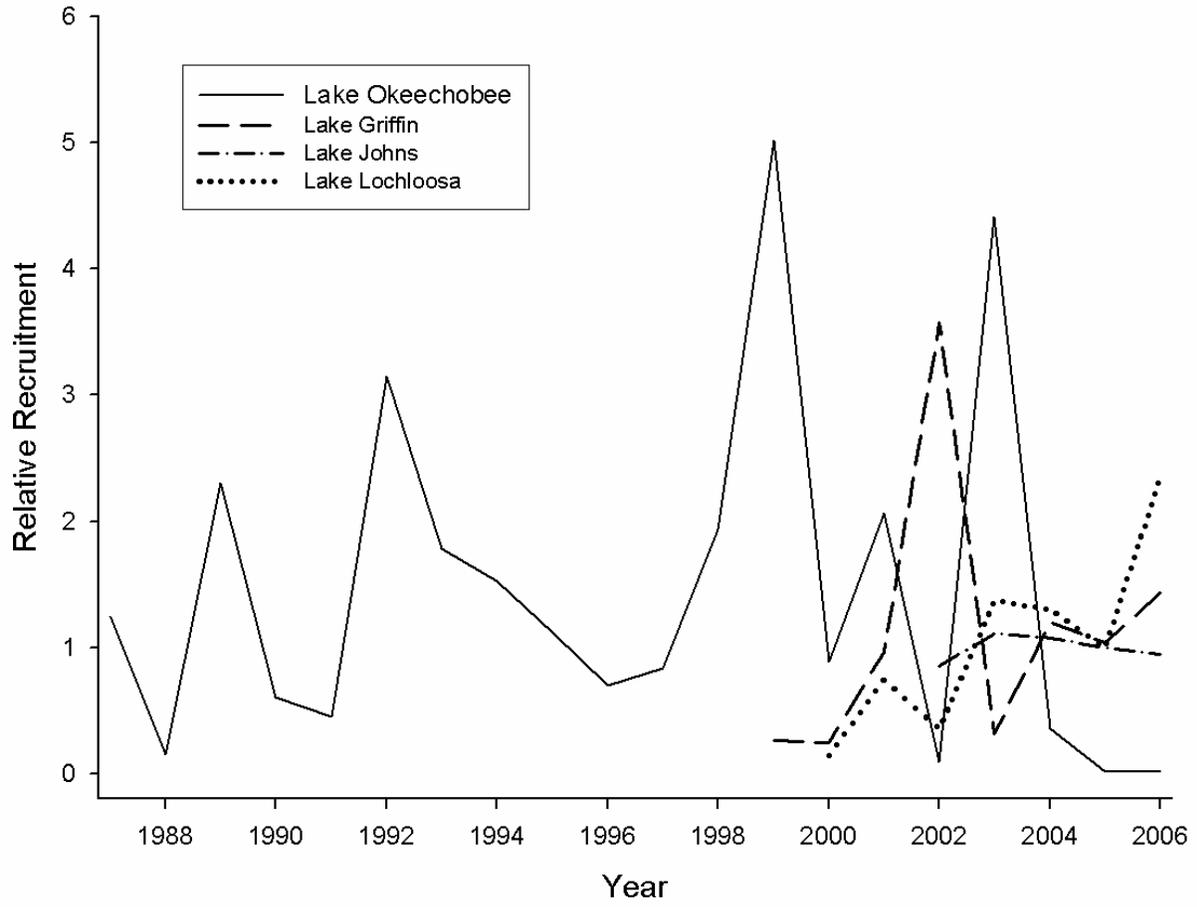


Figure 3-8. Observed time series of relative recruitment anomalies by lake.

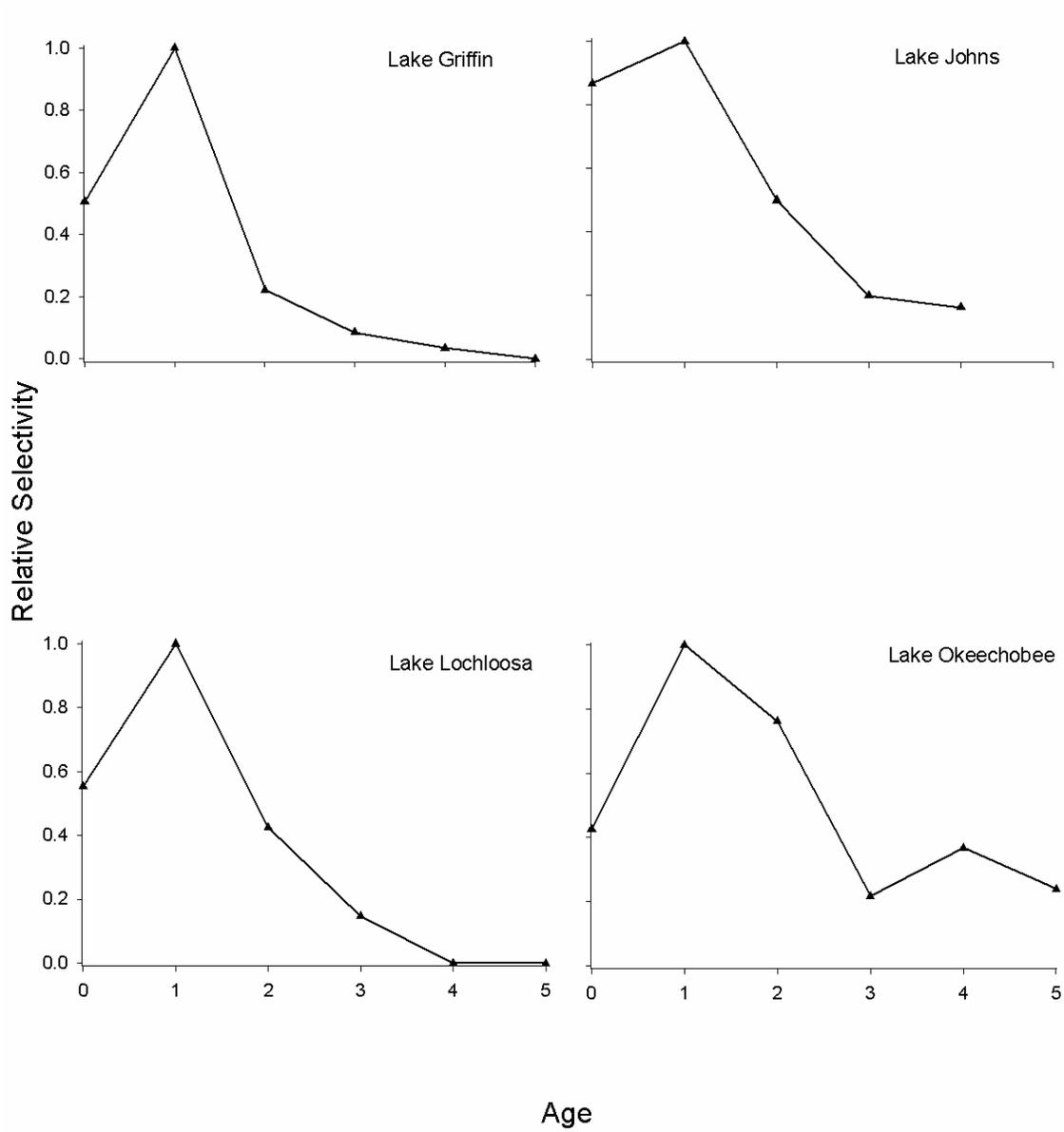


Figure 3-9. Relative selectivity by age for each study lake from base model

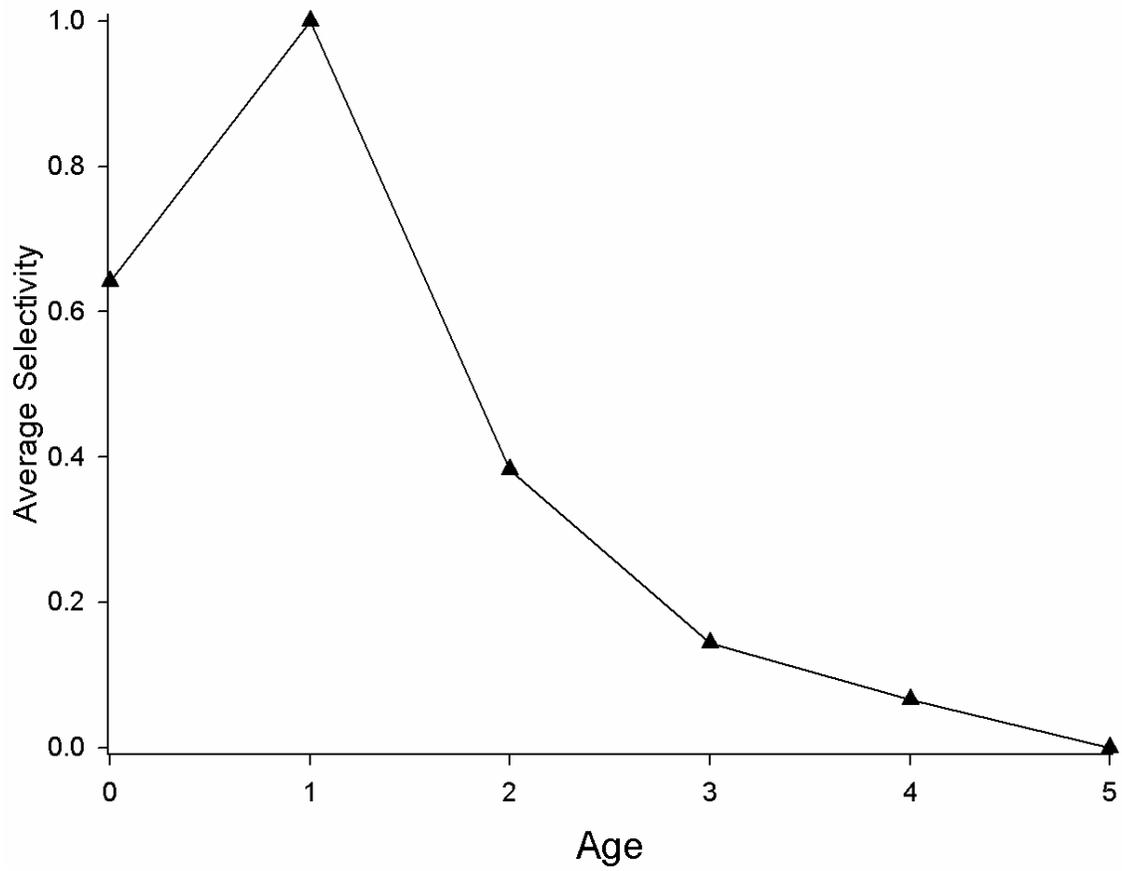


Figure 3-10. Average relative selectivity for lakes sampled with standard trawl (Lakes Griffin, Johns, and Lochloosa).

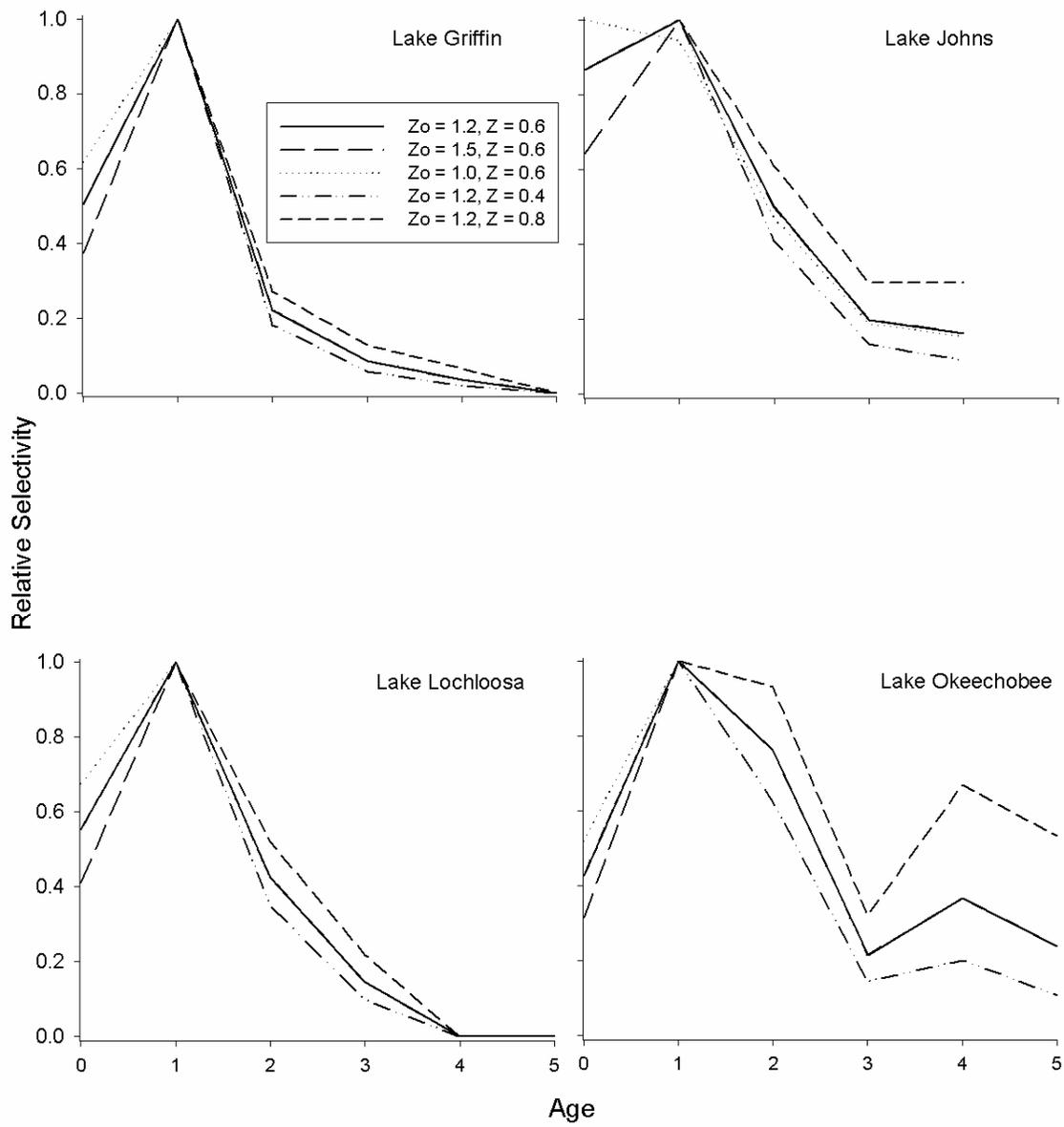


Figure 3-11. Relative selectivity by age under varying assumptions of survival.

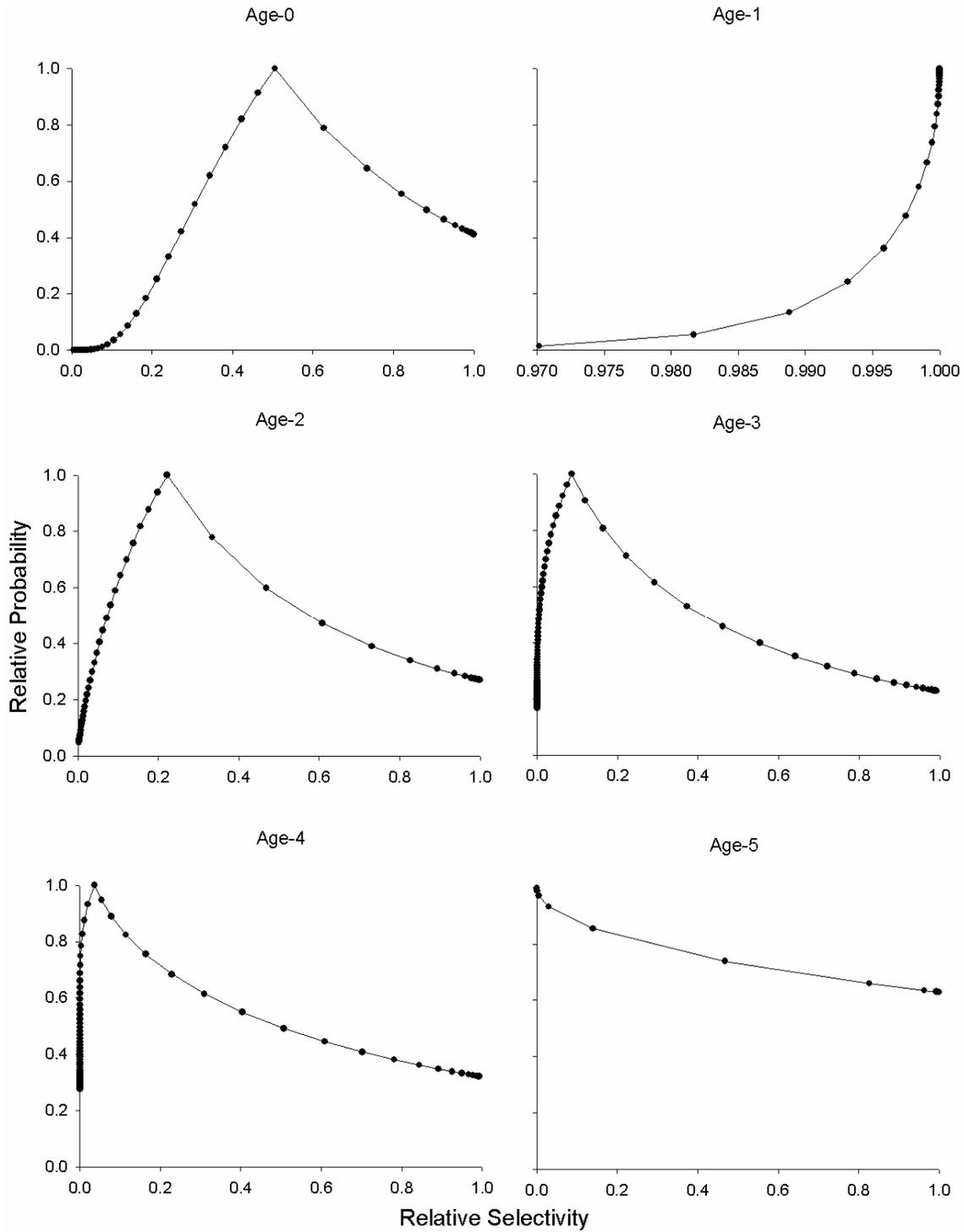


Figure 3-12. Lake Griffin probability profiles with relative selectivity on the x-axis and relative probability on the y-axis.

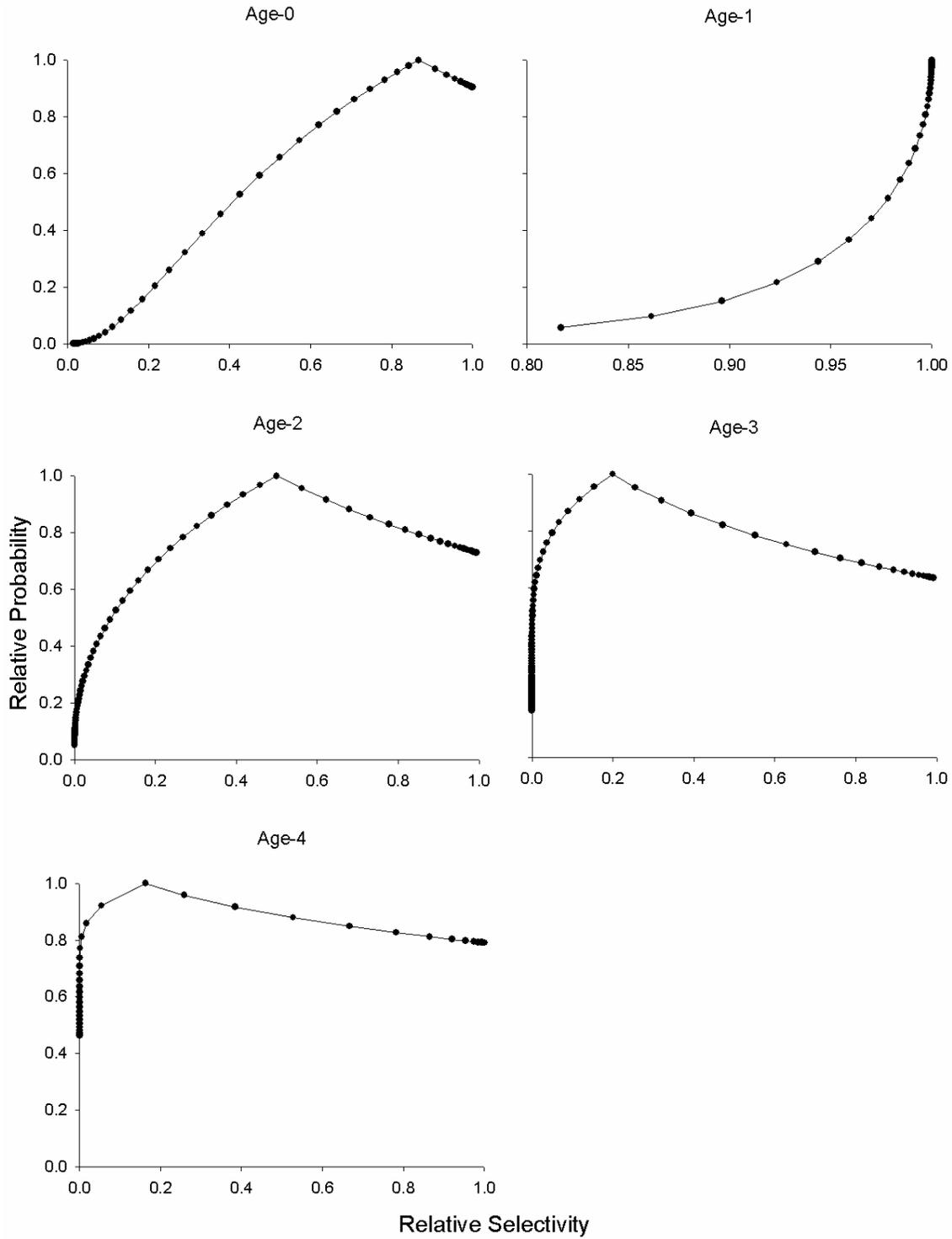


Figure 3-13. Lake Johns probability profiles with relative selectivity on the x-axis and relative probability on the y-axis.

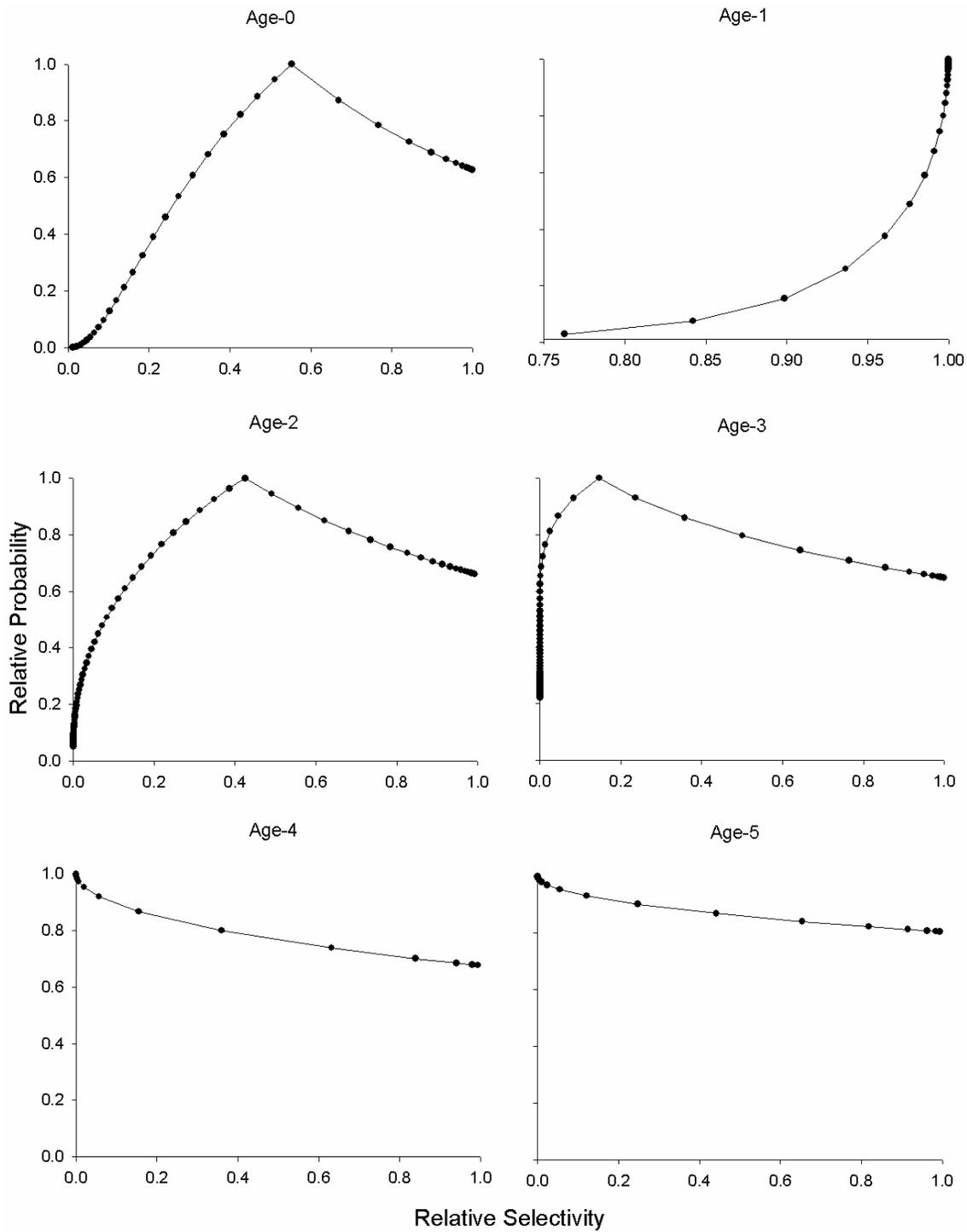


Figure 3-14. Lake Lochloosa probability profiles with relative selectivity on the x-axis and relative probability on the y-axis.

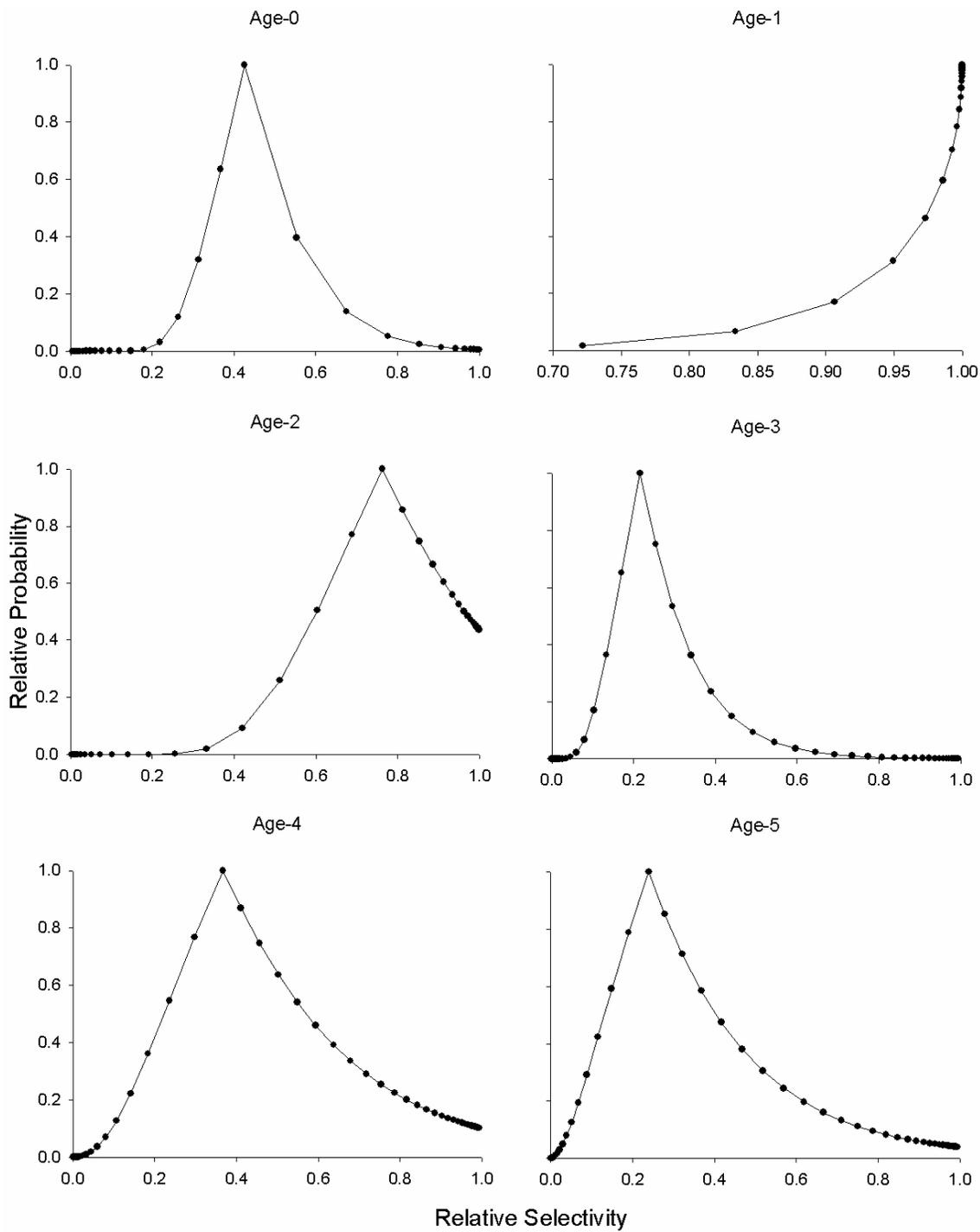


Figure 3-15. Lake Okeechobee probability profiles with relative selectivity on the x-axis and relative probability on the y-axis.

CHAPTER 4 DISCUSSION

Bottom trawls are an extremely efficient capture gear (reflected by large catches of various aquatic organisms and use in many fisheries worldwide), but often select for small finfish and crustaceans (Kjelson and Johnson 1978; Rulifson et al. 1992; Diamond et al. 1999). The size selectivity exhibited by bottom trawls results in large catches of small aquatic organisms (as evident by their use in commercial shrimp fisheries) and the incidental catch of commercially and recreationally important juvenile fishes (Howell and Langan 1992; Gallaway and Cole 1999; Diamond et al. 1999; Wakefield et al. 2007). My direct and indirect estimates of bottom trawl selectivity corroborated one another and indicated decreasing size selectivity with increasing length, suggesting that bottom trawls would be best for monitoring the abundance of small black crappie but may be inadequate to characterize the adult population. Catchability of black crappie has seldom been measured, but Miranda and Dorr (2000) found q with angling gear to vary with fish size. Furthermore, McInerney and Cross (2006) found q with trap-nets varied with size, season, and density and used these estimates to improve the interpretation of CPUE data to index abundance and describe size structures. My estimates of q lend insight into the size selective properties of bottom trawls for black crappie, and could be incorporated with catch data to index the true population age/size composition (e.g., Lake Jeffords).

My age-structured model simulations indicated dome-shaped selectivity to bottom trawls for black crappie and the highest selectivity estimates were for age-1 fish. Dome-shaped selectivity patterns are common for many sample gears and species (Erzini and Castro 1998; Jackson and Noble 1995; Miranda and Dorr 2000; Tanaka 2002), and evaluating differences in relative selectivity by age/size allows managers to adjust indices of abundance (Quinn and Deriso 1999) or determine gear efficiencies on the different age/size classes (Pierce et al. 1994).

Selectivity peaked at age-1 for all lakes under all scenarios except Lake Johns which exhibited decreasing relative selectivity with age when assumed age-0 survival was high. The results corroborate other selectivity studies (Jagiello 1999; Bayley and Austen 2002; McInerny and Cross 2006) and indicate the trawl gear may be most useful for tracking small-sized black crappie through time. Selectivity estimates exhibited high uncertainty except for age-1, but the observed selectivity patterns were similar across lakes. Individual selectivity estimates from my analyses should be viewed with caution, but the overall pattern of dome-shaped selectivity probably describes the general pattern of bottom trawl selectivity for black crappie.

Gear selectivity determines the effect of fishing on size/age structures. As such, assessment models can link size/age composition of catch data to size/age composition of the fishery (Taylor et al. 2005) to predict the effects of different harvest rates, calculate biological reference points, and identify maximum sustainable yields (Maunder 2002). Assuming constant catchability among size/age classes is a dangerous assumption and can lead to bias in yield models (Ricker 1975) because differences in age/size specific catchability to fishing gears can alter the maximum sustainable yield (MSY) obtainable from a fishery (Maunder 2002). When fishing mortality is restricted through effort controls, the catchability coefficient becomes a vital parameter in yield models, due to the relationship between q and yield and abundance.

Gear selectivity patterns and the cumulative effects of size-selective fishing practices often produce bias in length at age samples (Sinclair et al. 2002, Taylor et al. 2005). In exploited populations, fast growing young fish and slow growing older fish are overrepresented in length at age samples. In turn, this biases the parameter estimates of growth models used to describe mean length at age. My model results indicated bottom trawl selectivity for younger size/age-classes. Furthermore, all lakes in the study experience some level of angler exploitation. Thus,

since trawls appear more effective at capturing small fish and the older age-classes are exposed to harvest, growth models from trawl data collected from exploited populations may severely underestimate the asymptotic length (L_{∞}) and overestimate the metabolic growth coefficient (K). These inaccuracies can lead to biased mean length at age which would influence estimates of maximum yield and optimal harvest policies.

Age/size selectivity of sampling gears causes errors in the estimation of population structure (Walters and Hilborn 1992) and may limit the ability to draw inferences about trends in abundance. Therefore determining size selectivity of fishery independent assessment gears is important when survey CPUE data are used to index abundance, especially if assessment gears may not adequately sample the age and size range targeted by the fishery. For example, I found that large adult black crappies were poorly represented in bottom trawl samples, but these fish are targeted by recreational fisheries. Thus, bottom trawls may not detect changes in abundance even if large fish suffer high fishing mortality. This could lead to appearances of hyperstability (i.e., relatively constant CPUE over a large range of true fish abundance) because trawl catches of large black crappie could potentially be low and not change widely with changes in abundance.

When properly designed and implemented, mark-recapture studies can provide managers with information on growth, mortality, and reproduction, population size and structure, and gear selectivity (Seber 1982). Data for closed capture-recapture methods must meet several criteria. Foremost, the population of interest must be closed to additions and deletions. That is, recruitment, natural mortality, immigration, and emigration must be minimal. The immigration and emigration assumptions were probably not violated in my study due to the closed system and short time interval over which the study occurred. The mortality assumption was violated due to

tagging mortality but I adjusted for this in my calculations. Another assumption for mark recapture experiments is that marks are not lost or undetected by the recorder. Tag retention and detectability were likely very high in my study because I marked fish with a pelvic fin clip and sampled over a short interval before regeneration of fins could occur. A third requirement for closed mark recapture experiments is equal capture probability (i.e. no capture heterogeneity and/or trap response). Trap response is when capture probability is dependent on an animal's capture history, and is difficult to directly estimate (Pollock et al 1990). I estimated heterogeneity in capture probability as a function of fish size and account for potential trap responses by using different gear types for mark and recap events.

One potential cause of bias and uncertainty in q estimates from the mark-recapture experiment could be the higher observed sampling mortality for the smaller length-groups (90-119, 120-149) relative to the larger groups (150-179, 180+). This size selective mortality significantly reduced the number of fish available for recapture among those two groups. An overestimation in tagging mortality for these groups would cause a positive bias in my q estimates, resulting in more of an effect on trawl size selectivity. Alternately, underestimating sampling mortality could have caused a negative bias in the catchability estimates. The larger observed mortality on the smaller size groups could have resulted from high handling times and greater sampling stress on these classes relative to the larger length groups. The likelihood profiles also show there is more uncertainty in the likelihood estimate for the 90-119 size-group when compared to other groups. The larger variance can likely be attributed to the higher observed sampling mortality for this group. In turn, this influenced the number available for recapture (smaller N for this group) leading to a greater difference between observed and expected recaptures.

Differences in growth among the lakes could explain some of the differences in selectivity at age between lakes. Some lakes appeared to exhibit faster growth, which could have resulted in fewer numbers of faster growing individuals in the catch (as described above). This may have resulted in biased mean length at age for some lakes which may explain some of the observed differences in age-specific selectivities across systems. However, these differences appeared minimal because the overall pattern of dome-shaped selectivity occurred at all lakes.

My approximation of age-length keys using previous and post year data at Lake Lochloosa could pose problems in the estimated age structure and thus, the catch rate indices for those years. Inaccuracies in observed catch-at-age could have affected my proportions of catch-at-age and model fit having the potential to cause unknown biases in the selectivity estimates.

However, selectivity patterns for Lake Lochloosa were similar to those observed at the other lakes where age data were collected every year. Thus, I believe the selectivity patterns at Lake Lochloosa reflected real differences in across age-classes despite the gaps in the age structure data.

Furthermore, variation in mortality at size/age can affect the numbers in each age class available for capture leading to biased selectivity estimates. I accounted for this variability in survival to age by apportioning mortality into two classes (survival to age-1 and survival past age-1) based on life stanzas. I also simulated various levels of survival to show how different rates of survival on the age-classes could influence the numbers available for capture and thus, my selectivity estimates. I did not attempt to quantify exploitation rates on fish vulnerable to angling (\geq age-2) which may have decreased survival for some of the older age-classes relative to younger age-classes. If exploitation is high on older age-classes, the corresponding proportions of catch in those age-classes would decrease resulting in an increase in the younger

age-class proportions and an upward bias in the selectivity estimates for older/larger fish and a downward bias in selectivity estimates of younger/smaller fish. I assumed constant survival among years and did not evaluate the effects of changes in mortality between years. Changes in yearly natural and/or fishing mortality could significantly increase or reduce the numbers available for capture creating both positive and negative biases in selectivity estimates.

The indirect approach I used to estimate trawl selectivity is common data collected for recreational and/or commercially important fisheries. This methodology is quite common in marine assessments (Walters and Martell 2004), but examples are lacking for freshwater fisheries applications. I found this approach quite useful for estimating gear selectivity and recommend its application when catch-at-age time series data are available and when direct estimates are infeasible (e.g., large, open systems).

Use of my selectivity estimates should be restricted to similar seasons and lake types as used in this study. Size-selectivity of bottom trawls was evaluated during fall for the indirect method and winter for the direct method. Thus, the estimates provided may not apply to other seasons or times of the year. Seasonal effects on fish behavior are well documented (Pope and Willis 1996, Hayes et al. 1996) and sampling black crappie with bottom trawls at other times in the year may result in unknown bias in the CPUE index. Use of my selectivity estimates should be restricted to similar seasons from which they were derived. Lake characteristics and differences in geomorphology may have influenced my results. For example, gear efficiency and thus, catchability may vary due to differences in amount of suitable habitat, percent area coverage of macrophytes (PAC), depth, dissolved oxygen (DO) levels, substrate type or a variety of other factors. I did not attempt to quantify all of these effects and managers should be aware of these potential sources of bias and use the selectivity estimates with prudence. Furthermore,

systems selected for trawl sampling should be determined carefully to maximize efficiency and prevent gear fouling. Bottom trawl sampling may be an inappropriate gear on some lakes due to excessive bottom debris. Submerged debris, such as stumps or large amounts of aquatic macrophytes may prevent effective trawl sampling limiting sampling and/or gear efficiency.

The likely cause for size selectivity of smaller black crappie to otter trawls may be the ability of larger fish to detect or avoid the gear. Net avoidance and escapement after initial capture could result since swimming speed tends to increase with fish length (Helfman et al. 1997). Furthermore, gear avoidance by the larger fish may result due to the trawl pressure wake. This pressure wake may be detected due to larger and more developed lateral lines in larger fish. Spatial distributional patterns and habitat availability and use may also be a source for trawl selectivity. The smaller fish may utilize the pelagic zones of a lake and school more relative to large fish, where the larger fish may be more patchily distributed utilizing both open water and littoral areas of lakes. However, we controlled for differences in spatial distribution and habitat availability/use in the direct measure at Lake Jeffords, where crappie of all size ranges and the majority of fish were captured in open water habitats. Differences in spatial distribution patterns may have had more of an influence on the indirect selectivity estimates where there is likely a greater difference in habitat availability and use due to lake size and habitat complexity. However, the direct measure of selectivity suggests that the ability of larger fish to detect/avoid the gear is the likely source for trawl selectivity of younger/smaller crappie.

Stock assessments are important for fisheries management and attempt to recreate past stock trends to explain current stock trends and abundance by making quantitative predictions about the reactions of fish populations to alternative management options (Hilborn and Walters 1992). Therefore, bottom trawl catch data may be important for stock assessment analysis and

used for indices of recruitment, as measures of recruitment are one of the important inputs used for stock assessments. These data could be used in conjunction with another gear type that indexes the adult population (such as a creel) along with an estimate of fishing mortality to evaluate current stock trends facilitating the ability to make choices among policy options and evaluate the trade-offs associated with those decisions.

Otter trawls have been shown to effectively capture young black crappies (Allen et al. 1999, Pine 2000), and my results suggest that bottom trawls provided adequate catches of age-0 and age-1 fish. As such, otter trawls are probably most effective at tracking age-0 and age-1 abundances and can be used for estimates of year-class strength. However, my results suggested that the trawls may be inadequate to describe the adult population, fish growth rates, and age structure estimates due to substantially lower selectivity values for large fish. The selectivity estimates provided will allow managers to adjust abundance indices and correct age/size structures for relatively shallow Florida lakes.

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BIOGRAPHICAL SKETCH

Gregory Robert Binion was born on September 18, 1978, at a U.S. air force base in the United Kingdom, to Mike and Peggy Binion. Shortly after, he moved and was raised in San Antonio, Texas, with his older brother Pete. At a young age, he developed a passion for the outdoors and enjoyed much of his time exploring the wide open spaces and beautiful country of South Texas. He graduated from the University of Kentucky with a B.A. in political science in December 2002. Shortly after graduation, he relocated to Florida to pursue an interest in fisheries biology and management. In October 2003, he began to work as a fisheries technician on various projects at the University of Florida and began his graduate work at the Department of Fisheries and Aquatic Sciences at the University of Florida in January 2006. He will graduate with a Master of Science in December 2007. His future plans include traveling, passing time fishing and hunting, spending time with his family, and pursuing a career in fisheries management.