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A survey of Minnesota Department of Natural Resources area fisheries staff on methodology and use of fish age estimates

by

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Abstract — An in-house age and growth committee conducted a 16-question survey of Minnesota Department of Natural Resource (MNDNR) fisheries staff on how they estimate ages of fish collected during routine lake surveys and population assessments, how they use fish age and growth data, if staff are trained to estimate age of fish, and if they practice quality assurance and quality control (QA/QC) procedures to ensure data quality. Individual(s) from 23 of the 27 Area offices (Duluth and Lake Superior Areas were combined) answered most or all questions in this survey. Overall survey results suggested that Areas collect age and growth data for the same reasons and use these data to help make management decisions. However, methodology, including types of aging structures used and how aging structures are prepared before analyses, differed among Areas. Furthermore, emphasis on training, types of training, and QA/QC practices also differed among Areas. Because of these inconsistencies, integrity and utility of age and growth data collected by Areas is unknown. This committee recommends that MNDNR modify appropriate methodology within the Lake Survey Manual so that age and growth data are as accurate and precise as practical. Suggested changes include encouraging greater use of otoliths as aging structures, formal training of staff designated to do the age estimations, and adoption of QA/QC protocols. This committee also recommends that MNDNR should not make available any current statewide age and growth databases.

INTRODUCTION

The Minnesota Department of Natural Resources (MNDNR) is for a multitude of reasons re-evaluating its current methodology for estimating age and growth, as described in the most recent lake survey manual (LSM) (MNDNR 1993). These reasons include changes in techniques for estimating fish age and growth, development of a statewide data management system resulting in a more diverse array of end users of these data, increasing evidence of inconsistent age estimates, uncertainty in which age/growth metrics are estimated, and reductions in staff. These changes could make obsolete those guidelines for gathering age/growth data stated in the current LSM. The MNDNR adopted in 2007 a data management system that allows remote electronic entering of all age and growth data collected by each Area. Thus, statewide age/growth databases now exist for most game fish species sampled by MNDNR, and these data can be easily accessed by MNDNR staff as well as by people outside of MNDNR. However, it is unclear if data quality is sufficiently high to allow use by staff outside a given Area. Reductions in staff sizes without reducing workloads have also led MNDNR to search for opportunities to increase efficiency (i.e., focus on specific age/growth questions rather than collecting samples because it might be useful). This re-evaluation process included the formation of an in-house age/growth committee (authors of this report) in 2008 and tasked with evaluating age and growth methodology currently being practiced by MNDNR staff.

Based on informal interactions with MNDNR staff, we hypothesized that scales and pectoral spines (catfishes only) have been the primary structures used for estimating age of game fishes; thus, age estimates could be inconsistent and inaccurate, especially as fish age increases. Several internal studies clearly show that scale age estimates made by MNDNR staff have been inconsistent, and these inconsistencies increased with increasing fish age. Olson (1980) found between-reader agreement of annuli counts on scales was less than 11% for Walleye *Sander vitreus* estimated at age 6 or younger. Between-reader agreement of scale ages averaged 71% for age 4 and 60% for age 5 Black Crappie *Pomoxis nigromaculatus* and 62% for age 4 and 38% for age 5 White Crappie *P. annularis* among lakes across Minnesota (McInerny and Cross 2008). Stewig et al. (2010) reported between-reader agreement of scale ages for Bluegill *Lepomis macrochirus*, Walleye, and Yellow Perch *Perca flavescens* usually fell below 50% when scale ages exceeded age 3. Evaluations of pectoral spines of catfishes in Minnesota have not been done, but annuli counts on lapilli from Channel Catfish *Ictalurus punctatus* and Flathead Catfish *Pylodictis olivaris* outside of Minnesota provided more accurate and precise estimates of age than counts made on sectioned pectoral spines because lumens in spines of older catfish absorb early annuli (Nash and Irwin 1999; Buckmeier et al. 2002; Long and Stewart 2010).

In addition to scales, we knew MNDNR staff also used otoliths, cleithra, dorsal spines, or fin rays to estimate ages of game fish species. However, we did not know if each of these structures were used similarly among Areas. For example, collection of otoliths and cleithra require sacrificing of fish, and we did know that some staff were reluctant to kill fish for aging. Furthermore, guidelines in the LSM also discouraged sacrificing fish (MNDNR 1993). This reluctance in sacrificing fish coupled with low confidence in scale age estimates could contribute to increased use of dorsal spines and fin rays, which can be collected non-lethally.

We also lacked knowledge of how confident MNDNR staff are in their age estimates regardless of the aging structure being used. We hypothesized that staff had less confidence in their estimates made with scales because they appear inferior to other structures for estimating age. Age estimates from scales become increasingly inferior in accuracy or precision with increasing age compared to ages estimated from sectioned or cracked sagittal otoliths for Brook Trout *Salvelinus fontinalis*, Lake Trout *S. namaycush*, Smallmouth Bass *Micropterus dolomieu*, Largemouth Bass *M. salmoides*, Walleye, and Yellow Perch (Erickson 1983; Sharp and Bernard 1988; Hall 1991; Robillard and Marsden 1996; Niewinski and Ferreri 1999; Long and Fisher 2001; Bruesewitz et al. 2002; Buckmeier and Howells 2003; Stolarski and Hartman 2008). Annuli counts on whole views of otoliths appear more precise than those on scales for Bluegill, White Crappie, Black Crappie, and Walleye (Hoxmeier et al. 2001; Isermann et al. 2003; Ross et al. 2005). Cleithra appear superior to scales for estimating age of esocids when age estimates differ between these two structures (Harrison and

Hadley 1979; Laine et al. 1991). Estimating ages from annuli counts on cross sections of dorsal spines appears useful for estimating ages of Walleye and Yellow Perch younger than age 7 but could lack value for estimating age of Largemouth Bass (Maraldo and MacCrimmon 1979; Niewinski and Ferreri 1999; Logsdon 2007). Age estimates based on annuli counts of cross sections of pectoral fin rays appear less precise than the same estimates made with scales of Brook Trout (Stolarski and Hartman 2008).

Statewide databases are useful only if data quality is high; however, we did not know if and to what degree quality assurance and quality control (QA/QC) are practiced by MNDNR staff. Examples of QA/QC include the use of blind reads (estimating age without aids such as time of capture, length-frequency distributions, stocking records, etc.) of structures, two or more people providing age estimates from the same structures (second reads), training of staff, and use of known-age fish. We knew that no formal training of staff occurred within MNDNR; however, we did not know if informal training occurred within Areas. Additionally, all 28 Areas make fish sampling decisions for Area needs rather than for statewide needs; thus, this difference in scope could also affect the quality of statewide age/growth databases.

Quality of age and growth data could also be affected by different methods used by various staff to process the same type of aging structure, and resolution of annuli could differ between processing methods. For example, we knew that some staff made scale impressions on acetate before reading while others viewed un-pressed scales under a microscope or via a microfiche reader. We thought that most MNDNR staff that collect otoliths expose the kernel area by breaking the otolith in half rather than using a saw to section thinner pieces that include the kernel area. Furthermore, we also know that some staff that break otoliths also burn via a flame the kernel area before reading while others read unburnt otoliths. Lastly, MNDNR staff using dorsal spines either sectioned them or they snapped them in half and supported in clay before counting annuli.

Reports of MNDNR lake surveys and population assessments usually contain tables showing back-calculated lengths at annulus formation, and we assumed that nearly all of these are based on scale measurements. However, similar estimates can be made from any structure in which growth increments can be measured (Casselman 1990). Thus, it is possible that some staff estimate back-calculated lengths at age using structures other than scales. We also learned that some staff use a combination of otolith age estimates and scale measurements to estimate back-calculated lengths at age because they have more confidence in the otolith age. This practice probably works for estimating lengths of younger ages if aging errors occur at the scale edge, but biased measurements could result if aging errors occur near the scale focus.

Because all of these above observations were based on informal conversations with some MNDNR staff, we cannot conclude with certainty that they reflect the entire department. Furthermore, we do not know which metrics are being estimated with age and growth data and whether or not staff even collect aging structures. Therefore, we decided to conduct an internal formal survey designed to determine which age and growth metrics are being estimated, if methodology is consistent, and if QA/QC protocols are being practiced by MNDNR staff. If survey results suggest that methodology, training, and QA/QC are consistent and effective, then development of statewide databases of age and growth should occur and changes in the LSM could be minimal. If not, then development of these databases should be discouraged until effective changes are made to improve consistency and quality of data.

METHODS

A 16-question survey was sent to 27 Area offices (Duluth and Lake Superior Areas were treated as one) on May 31, 2011, and they were asked to complete the survey within two weeks. To facilitate completion of this survey, 11 questions were closed-ended, two others were closed-ended if the answer was ‘no’ but open-ended if the answer was ‘yes’, one was close-ended if choices other than ‘other’ were made, and two were fully open-ended (Table 1). These questions were designed to determine reasons for collecting age and growth data, types of aging structures collected from each species, methods for processing these structures, confidence in age and growth estimations of each species, if training occurs and is similar, and if QA/QC is practiced and how. We added the open-ended Question 16 in case questions were poorly stated or misinterpreted, or if we failed to include in close-ended questions other appropriate choices. Thus, this question allowed respondents to clarify their answers as well as add any other details on aging they felt important.

For most questions, data reported from close-ended questions were reported as the percent of respondents that picked a particular choice. If open-ended questions clearly revealed a choice(s) not listed in the appropriate closed-ended question, it (they) was added as another choice, and percentages of respondents picking that new choice(s) was also calculated. Attempts were made to partition into categories responses in open-ended Questions 2, 3a, and 6a; these were reported as frequencies because respondents oftentimes listed multiple items that fit more than one category. Other items reported in Question 16 were listed within the appropriate paragraph in the Results and Discussion section.

TABLE 1. List of age and growth based questions asked in a survey of Minnesota Department of Natural Resources Area staff done on 31 May 2011.

Question	Possible responses
1). Does your office age fish?	Yes or no
2). What does your office use aging data for?	Open-ended
3). Does your office use aging data for management decisions or set management goals?	Yes or no
3a). If answer to question 3 is yes, what metrics are used?	Open-ended
4). How confident are you about your aging data collected by your office?	Very, somewhat, or not
5). In your office, how many people routinely age fish?	0, 1, 2, or > 2
6). Does your office train all staff to age fish the same way?	Yes or no
6a). If answer to question 6 is yes, what methods (i.e., on the job training, training manuals, etc.) are used?	Open-ended
7). For each species (Brown Trout, Brook Trout, Lake Trout, Northern Pike, Channel Catfish, Flathead Catfish, Bluegill, Smallmouth Bass, Largemouth Bass, Black Crappie, Yellow Perch, or Walleye), please indicate which structure is used for aging.	Scale, otolith, spine/fin ray, or don’t age
8). What is the maximum age that you feel confident aging each of these species using your preferred structure?	0-5 years, 5-10 years, or > 10 years
9). Does your office conduct blind reads (i.e. does not use other information such as fish length, sex, maturity, stocking records, date of capture, etc.)	Yes or no
10). Does your office perform second reads for quality assurance and quality control?	Yes or no
11). When using scales, does your office press them in acetate or read them directly under a microscope or microfiche reader?	Press, not press, or other (please explain)
12). When using otoliths, how are they read?	Whole view, cracked, cracked-burned, or combination of these three.
13). When using spines or fin rays, how are they read?	Sectioned, or cracked and placed in clay (similar to otoliths)
14). Does your office age otoliths first, and then collect scale measurements for back-calculation?	Yes or no
15). Does your office collect from otoliths, spines, or fin rays data for back-calculations?	Yes or no
16). Please provide any additional comments about your office’s aging procedures that you think are important	Open-ended

RESULTS AND DISCUSSION

Most Area offices provided responses to this survey, and they provided several reasons for acquiring age and growth data. Staff from 23 (85%) of the 27 Area offices answered all or nearly all questions in this survey; no responses came from Aitkin, Brainerd, Hinckley, or Lanesboro Areas. Informal conversations with staff at Aitkin, Brainerd, and Hinckley Areas revealed that these Areas also estimate with one or more structures age and growth of fish; thus, results from this survey probably apply to these Areas. Conversely, the Lanesboro Area marks with passive integrated transponder tags age 0 Brown Trout and Brook Trout and relies on recaptures in subsequent sampling to obtain their age and growth estimates (Dieterman et al. 2012).

Results indicated that staff from each of the 23 responding Area offices estimate age and growth of fish. Based on Question 2, the most common data sought are estimates of growth, age distribution, year-class strengths, and documenting presence/absence of specific year-classes or natural reproduction (Table 1; Figure 1).

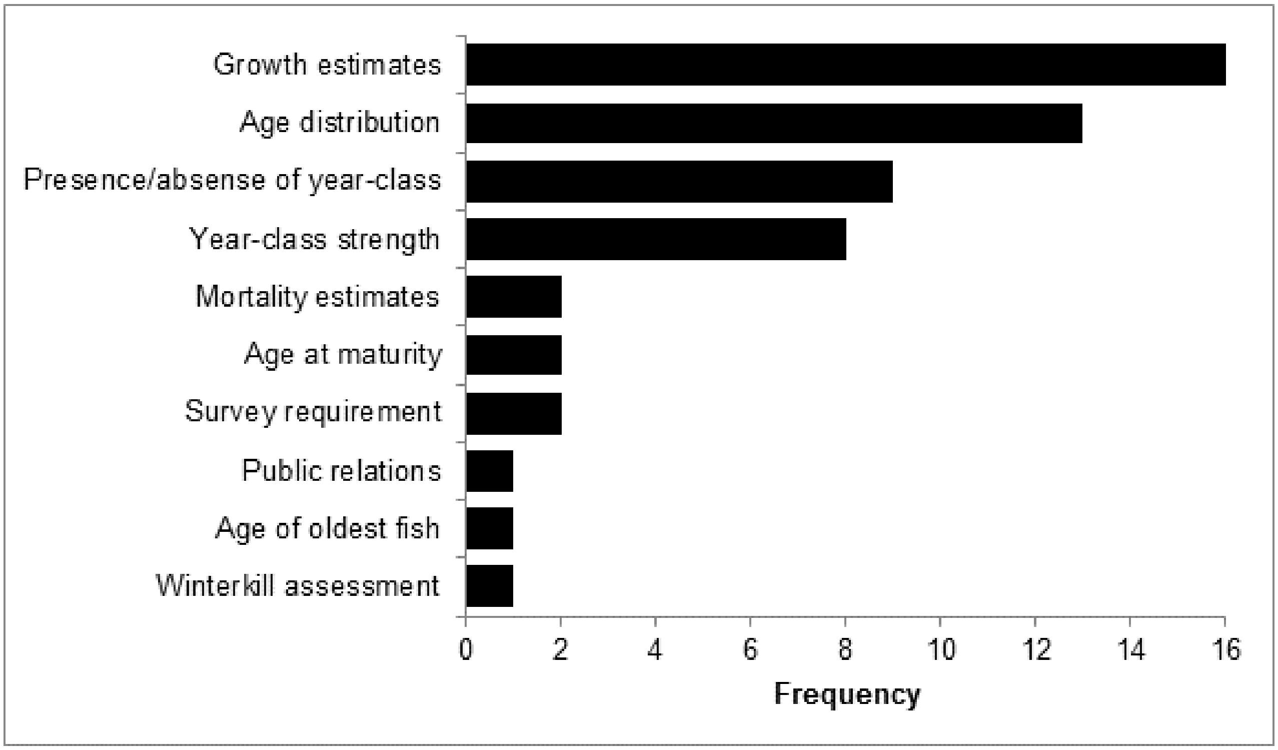

FIGURE 1. List and frequency of reasons Minnesota Department of Natural Resources Area offices collect age and growth data during lake surveys and population assessments (Question 2 in Table 1).

Staff at 21 (91%) of the 23 Area offices reported that they use age and growth metrics for making fisheries management decisions. Based on Question 3a, these data are primarily used to help assess the quality or health of fish populations, help evaluate stocking success (usually Walleye), or help evaluate success of special or experimental regulations (Table 1; Figure 2).

This survey suggested that MNDNR estimates ages of at least 18 fish species and taxa across Minnesota. Over 90% of the responding Areas estimate age and growth of Northern Pike *Esox lucius*, Bluegill, Largemouth Bass, crappies, and Walleye, but less than 20% estimate age and growth of Brown Trout *Salmo trutta*, Brook Trout, Lake Trout, and Flathead Catfish (Figure 3). Based on Question 16, one or more Area offices also estimate age and growth of Rainbow Trout *Oncorhynchus mykiss*, splake, Lake Whitefish *Coregonus clupeaformis*, Muskellunge *Esox masquinongy*, or Common Carp *Cyprinus carpio*. Some of these variable percentages among taxa probably reflect their spatial distributions within Minnesota.

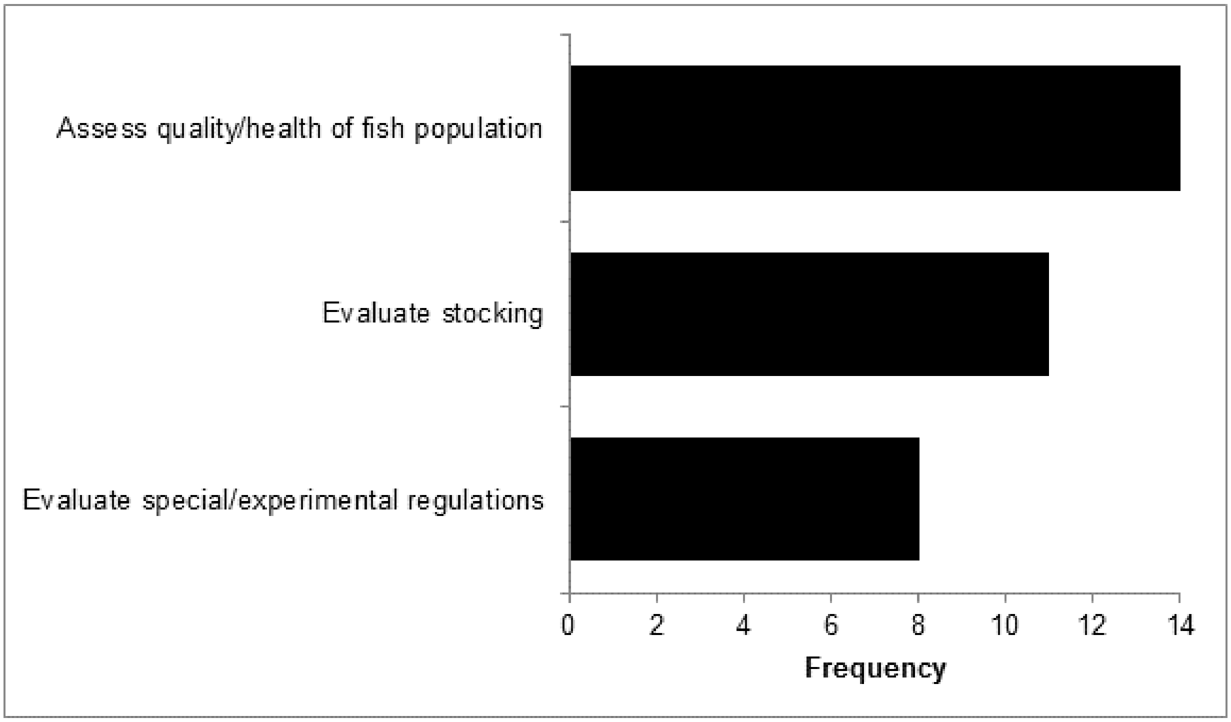

FIGURE 2. Categories of fisheries management activities requiring age and growth data and frequency of these categories listed during a survey of Minnesota Department of Natural Resources Area offices (Question 3a in Table 1).

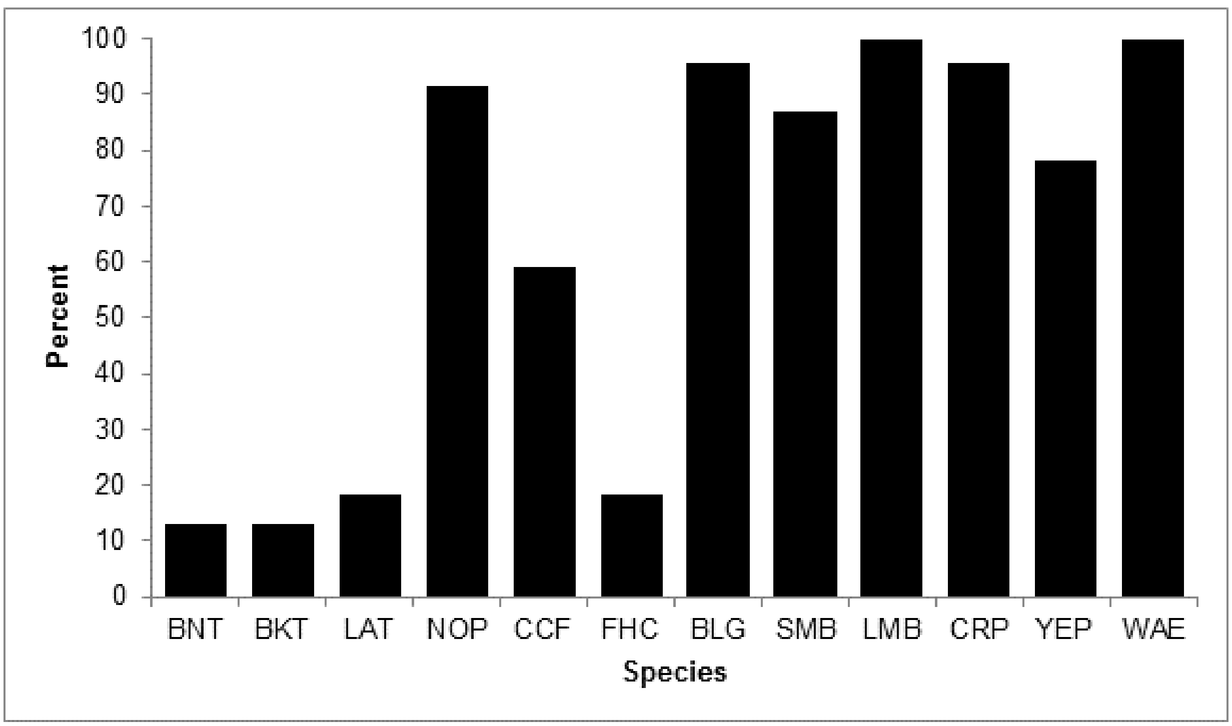

FIGURE 3. Percent of Minnesota Department of Natural Resources Area offices (n = 23) that estimate age of Brown Trout (BNT), Brook Trout (BKT), Lake Trout (LAT), Northern Pike (NOP), Channel Catfish (CCF), Flathead Catfish (FHC), Bluegill (BLG), Smallmouth Bass (SMB), Largemouth Bass (LMB), crappie (CRP), Yellow Perch (YEP), and Walleye (WAE) (derived from Question 7 in Table 1).

Most Areas relied on scales to provide age and growth data of most taxa they sample except for catfishes, Lake Trout and Walleye (Figure 4). More Areas used otoliths rather than other structures to estimate age of Lake Trout and Walleye, and pectoral spines were the only structure used to estimate age of Channel Catfish and Flathead Catfish. Relatively few Areas collected otoliths in conjunction with scales (Figure 4). Responses in Question 16 suggested that at least one third of Areas collected cleithra from Northern Pike, and at least one Area collected opercular bones from Largemouth Bass, Smallmouth Bass, and Walleye. In addition to using scales, one Area also used cleithra and another Area used anal fin rays to estimate age of Muskellunge. Another Area used both scales and otoliths to estimate age of coregonids.

Methods of structure preparation before estimating age also differed among Areas. Half of the Areas made scale impressions on acetate before counting annuli and measuring scale increments; however, about one fourth read scales directly without making impressions and about one fourth used a combination of both methods (Figure 5). Those Areas using both methods read un-pressed scales of small fish, but, for longer fish, they made scale impressions on acetate. When using otoliths, most Areas estimated age with the crack-and-burn method or some combination of whole view, cracked-only, and crack-and-burn (Figure 6). None of the Areas used the cracked-only method exclusively. Two Areas sectioned otoliths before counting annuli. Based on Question 13, 85% of Areas estimating age from spines or fin rays sectioned them before placing them under a dissecting microscope for counting annuli. The remaining 15% snapped spines in half and then placed them (snapped side up) in clay. Additionally, comments in Question 16 suggested that at least two Area offices sectioned spines, but polished the exposed end before placing them in either cardboard or clay.

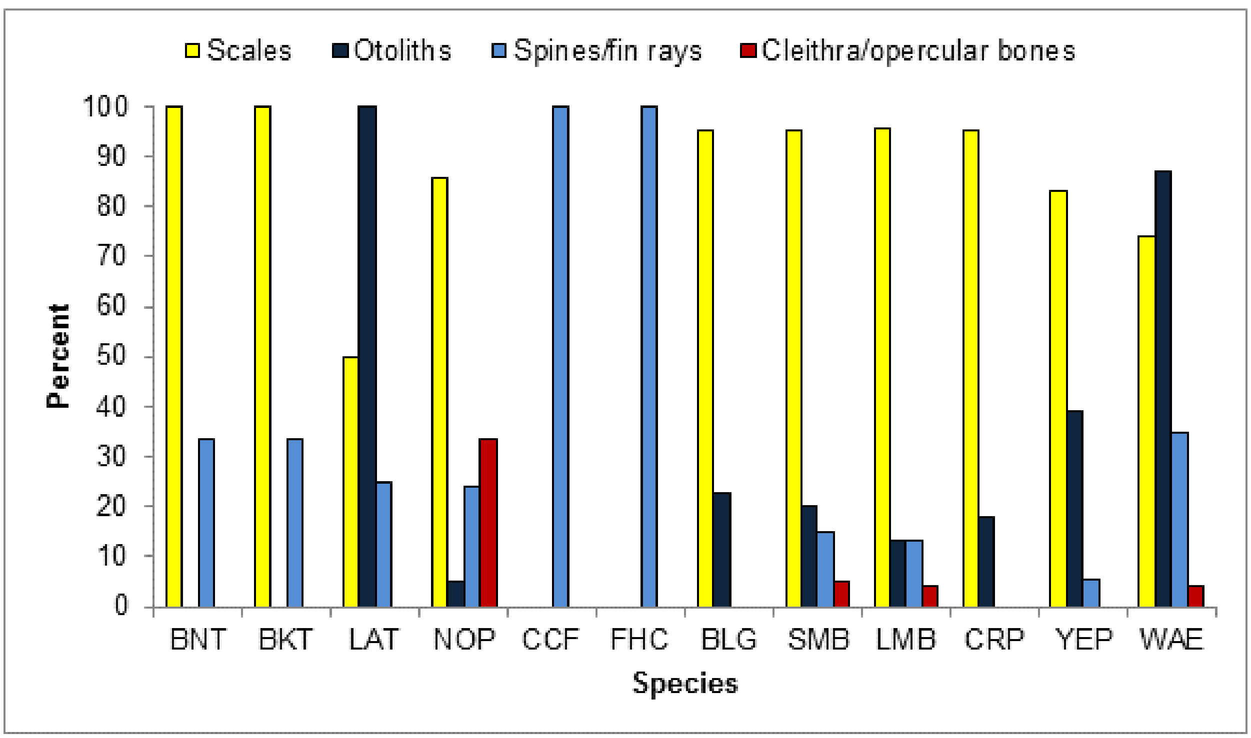

FIGURE 4. Percent of Minnesota Department of Natural Resources Area offices (n = 23) using scales, otoliths, spines/fin rays, or cleithra/opercular bones for estimating age of Brown Trout (BNT), Brook Trout (BKT), Lake Trout (LAT), Northern Pike (NOP), Channel Catfish (CCF), Flathead Catfish (FHC), Bluegill (BLG), Smallmouth Bass (SMB), Largemouth Bass (LMB), crappie (CRP), Yellow Perch (YEP), and Walleye (WAE) (Question 7 in Table 1).

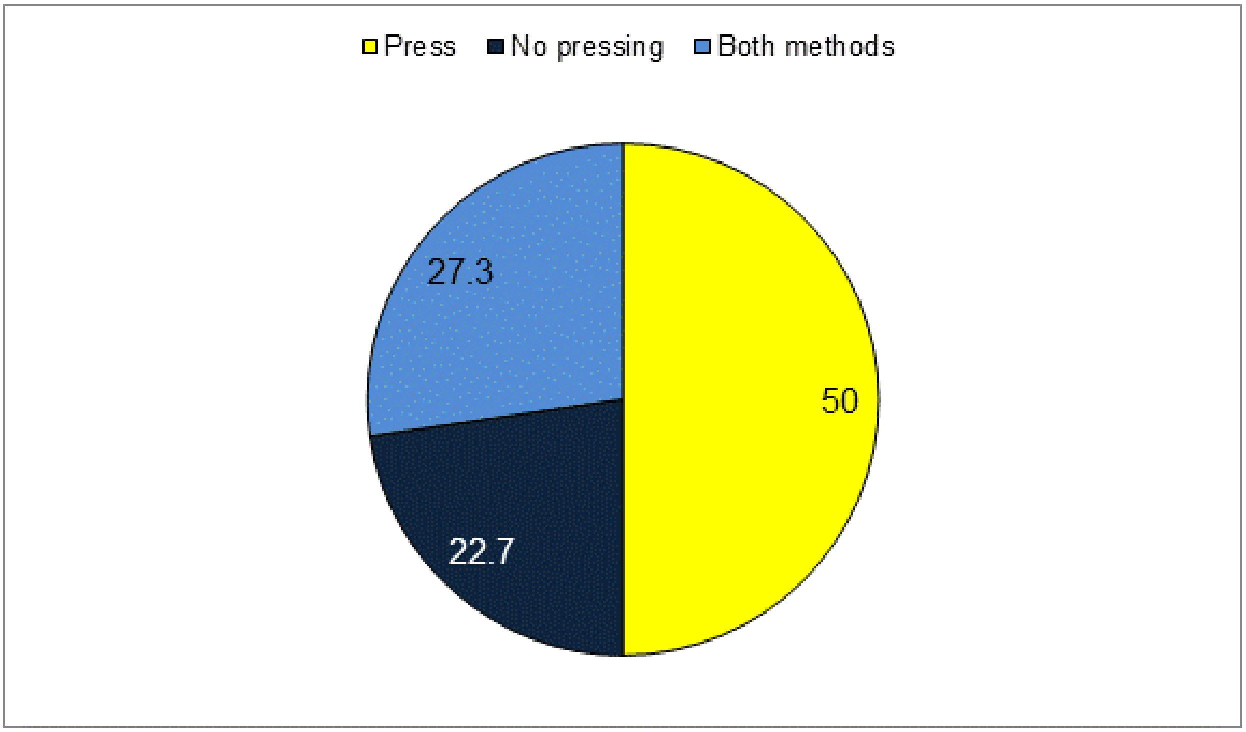

FIGURE 5. Percent of Minnesota Department of Natural Resources Area offices (n = 22) that make scale impressions on acetate (press) before estimating age, estimate age by reading scales directly (no pressing), or using a combination of pressing and no pressing (both methods) (Question 11 in Table 1).

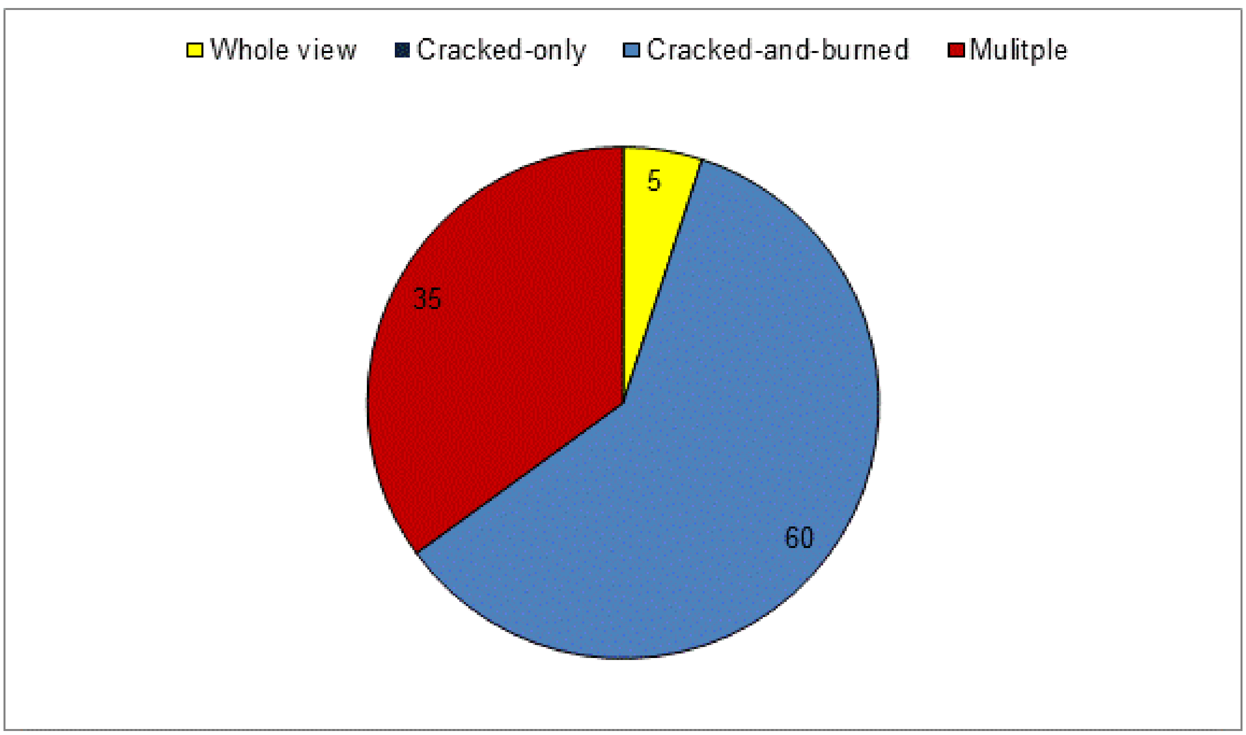

FIGURE 6. Percent of Minnesota Department of Natural Resources Area offices (n = 20) which collect otoliths that read them via whole view only, cracked-only, cracked-and-burned, or read via a combination of these three methods (multiple) (Question 12 in Table 1).

Areas showed variable confidence in their age and growth estimates, and confidence varied among taxa and the range of ages estimated. However, Areas probably did not interpret the term 'confidence' similarly. Most Areas felt very confident, but no Area completely lacked confidence about their age and growth data (Figure 7). More than half the Areas felt confident about age estimates of Brown Trout, Brook Trout, and Northern Pike ranging from zero to five years of age (Figure 8). However, at least three Areas expressed, via Question 16, that they lacked confidence in age estimates of Northern Pike regardless if age was estimated with scales or cleithra, and one Area reported having more confidence in age estimated with cleithra than scales. At least half of the Areas felt confident about age estimates of Lake Trout, Bluegill, Largemouth Bass, Smallmouth Bass, and crappies when age estimates ranged from 5 to 10 years (Figure 8). Equal percentages (44%) of Areas felt confident if age of Yellow Perch was between zero and 5 years or between 5 and 10 years (Figure 8). Most Areas felt confident about age estimates of Channel Catfish older than 4 and Flathead Catfish older than 9. Slightly more than half of the Areas felt confident in their Walleye ages exceeding age 10 (Figure 8). Other comments expressed in Question 16 indicated that at least one Area believed the following: otolith age estimates exceeding age 10 but did not believe scale age estimates exceeding age 5, scale age estimates exceeding age 10 in some populations but only to ages 5 to 7 in others, their spine age estimates were more accurate than their scale age estimates, or their age estimates of the oldest fish sampled were inaccurate. Opinions expressed in the survey also suggested that 'confidence' meant 'accuracy' by some but at least one response suggested that 'confidence' meant 'close enough'.

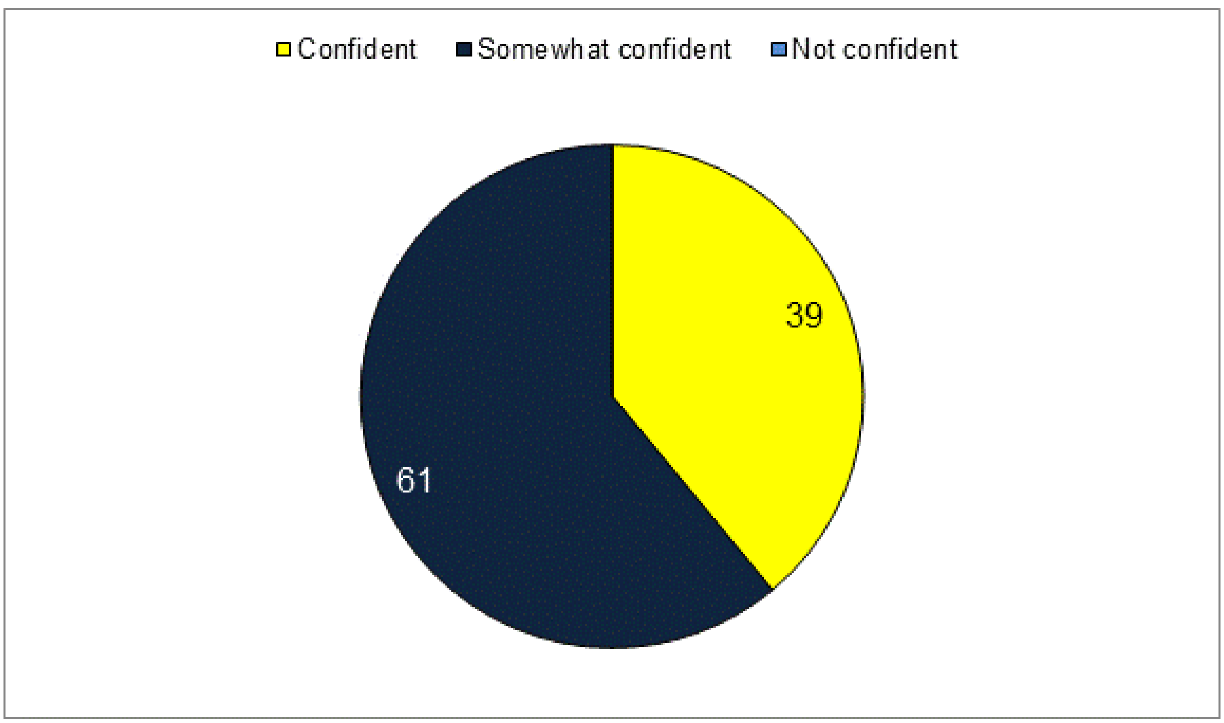

FIGURE 7. Percent of Minnesota Department of Natural Resources Area offices (n = 23) that are confident, somewhat confident, or not confident with their aging data (Question 4 in Table 1).

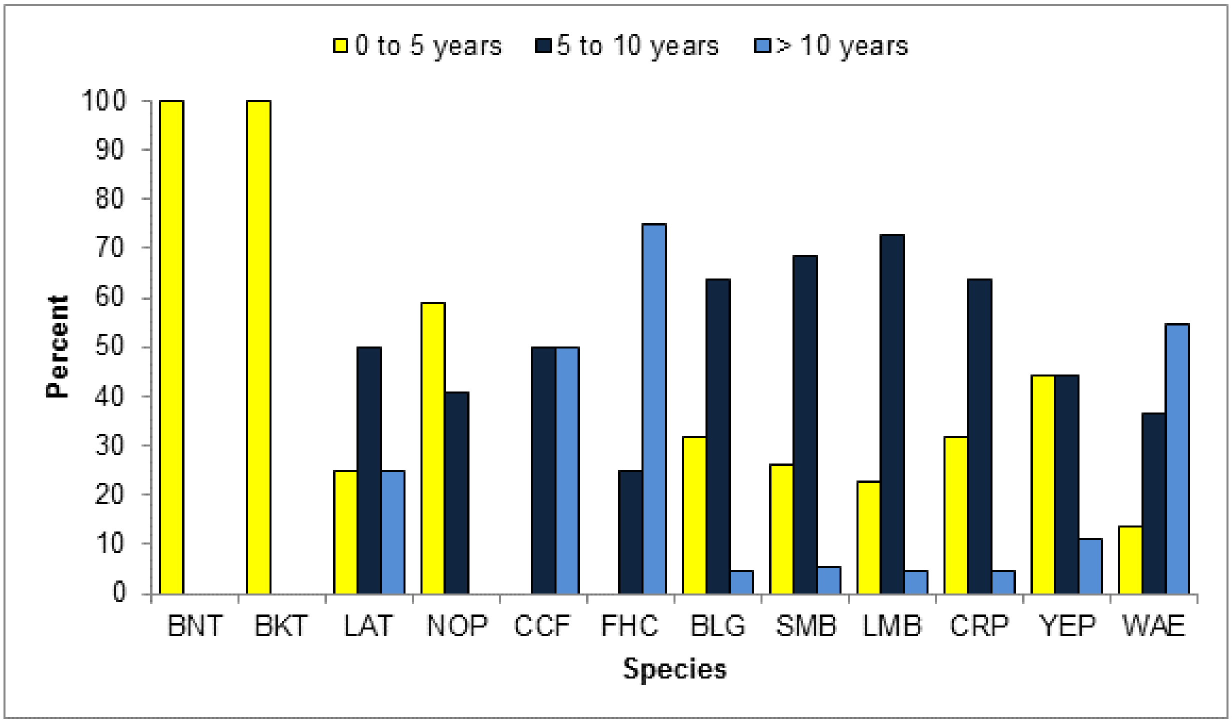

FIGURE 8. Percent of Minnesota Department of Natural Resources Area offices (n = 22) that feel confident that age estimates of Brown Trout (BNT), Brook Trout (BKT), Lake Trout (LAT), Northern Pike (NOP), Channel Catfish (CCF), Flathead Catfish (FHC), Bluegill (BLG), Smallmouth Bass (SMB), Largemouth Bass (LMB), crappie (CRP), Yellow Perch (YEP), and Walleye (WAE) are accurate from 0 to 5 years, 5 to 10 years, or older than 10 years (Question 8 in Table 1).

Most Areas estimate back-calculated lengths at annulus formation, but they did not always follow similar methodology. According to responses in Questions 14 and 15, nearly all (22 of 23; 96%) Areas estimated back-calculated lengths at age, and 20 of 22 (91%) made these estimates from scale measurements only. Responses to Question 15 suggested that 13 (59%) of 22 Areas first estimate age by counting annuli on otoliths and then measured growth increments on the appropriate scales; the other nine Areas did not.

This survey also suggested that emphasis on training and QA/QC differed among Areas and often appeared lax. Most (21 of 23; 91%) Areas assigned at least two staff to estimate ages (Figure 9), but responses to Question 6 suggest that only about one-half (12 of 23) of Areas trained staff similarly. Most (13 of 17) Areas answering Question 6a reported that experienced co-workers trained inexperienced co-workers (Figure 10). Training manuals were sometimes used, and 'comparisons with peers', and 'the same two people estimated age of all fish' was each mentioned once (Figure 10). Only eight (36%) of 22 Areas perform second reads for QA/QC. Responses in Question 16 revealed that second reads were also part of the training process for inexperienced agers or were performed when one individual sought an opinion of another for a specific case. Additionally, some Areas discontinued second reads because of decreased staff size or because disagreements in age estimates often remained unresolved. Lastly, only four (18%) of 22 Areas reported they conduct blind reads of aging structures.

Inclusion of open-ended questions revealed additional practices and viewpoints that would not have been revealed if only our close-ended questions were used. Those percentages and frequencies reported for closed-ended questions would have differed somewhat if close-ended questions were more inclusive, but overall conclusions about the lack of consistency in methods, training, and QA/QC would be the same.

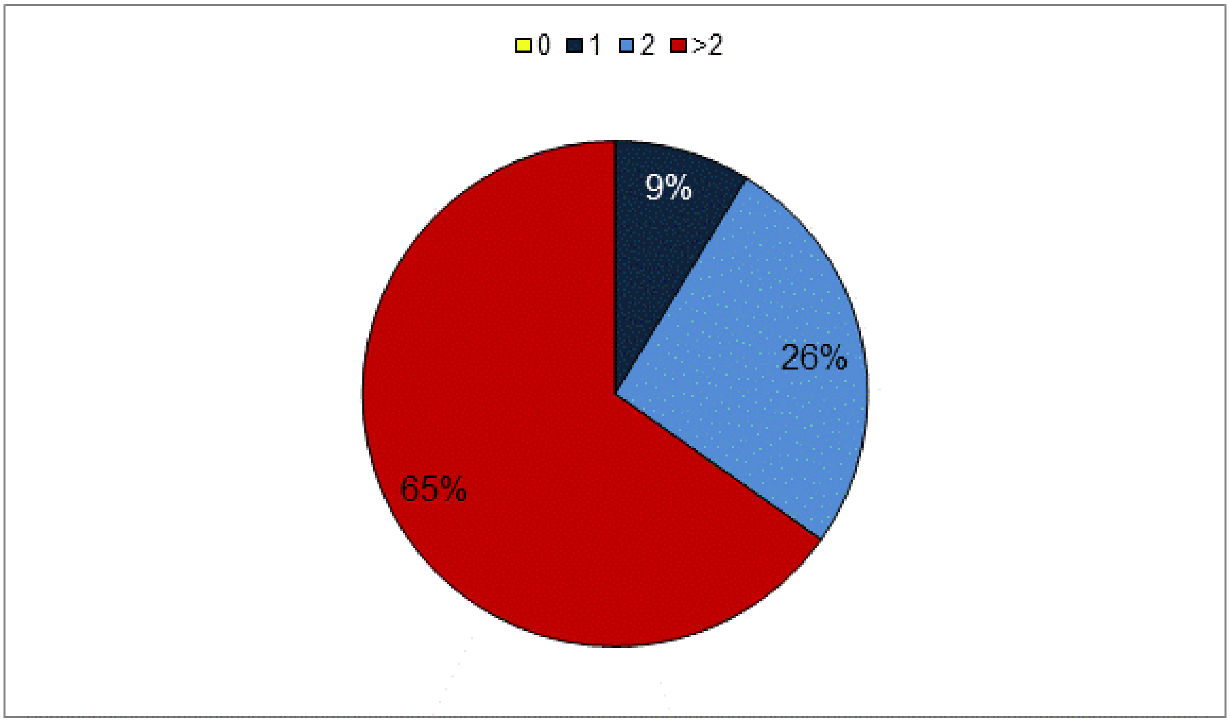

FIGURE 9. Percent of Minnesota Department of Natural Resources Area offices (n = 23) in which zero, one, two, or more than two staff estimate age of fish (Question 5 in Table 1).

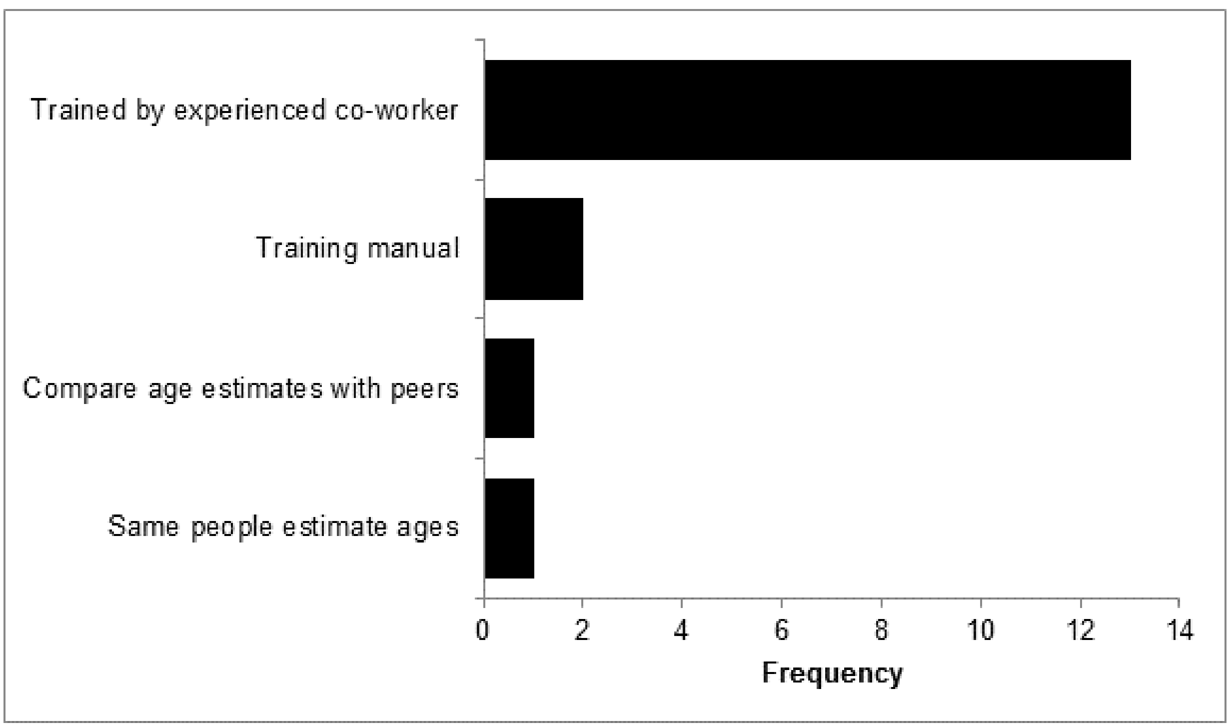

FIGURE 10. List of methods used by Minnesota Department of Natural Resources Area offices for training staff to estimate age and growth of fish, and the frequency of Areas using these methods (Question 6a in Table 1).

RECOMMENDATIONS

We recommend that the methodology within the LSM be modified to ensure that ages are estimated with as high of precision as practical. These modifications should include, but not limited to, requiring the use of otoliths as primary aging structures whenever practical, formal training, and adoption of QA/QC procedures. Doing so increases odds that scientifically sound fisheries management decisions are made and will also provide useful statewide databases on age and growth. We also recommend that current statewide databases on age and growth be withheld from use by individuals outside the Area where collected. Lastly, if scales and pectoral spines remain as primary aging structures, we recommend that for each game species age structure comparisons be made that include age estimates from either sectioned or cracked otoliths. These comparisons will identify the optimal range of ages that can be reliably estimated with scales and spines, and because otolith age has been validated as accurate for many species.

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LITERATURE CITED

Bruesewitz, R. E., T. Jones, and B. Borkholder. 2002. Comparison of aging structures from Walleye at Mille Lacs and Ann lakes, Minnesota. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Study 4 Report, Job 537, St. Paul.

Buckmeier, D. L., E. R. Irwin, R. K. Betsill, and J. A. Prentice. 2002. Validity of otoliths and pectoral spines for estimating ages of Channel Catfish. North American Journal of Fisheries Management 22:934-942.

Buckmeier, D. L., and R. G. Howells. 2003. Validation of otoliths for estimating ages of Largemouth Bass to 16 years. North American Journal of Fisheries Management 23:590-593.

Casselman, J. M. 1990. Growth and relative size of calcified structures of fish. Transactions of the American Fisheries Society 119:673-688.

Dieterman, D. J., R. J. H. Hoxmeier, and D. F. Staples. 2012. Factors influencing growth of individual Brown Trout in three streams of the upper Midwestern United States. Ecology of Freshwater Fish 21:483-493.

Erickson, C. M., 1983. Age determination of Manitoban Walleyes using otoliths, dorsal spines, and scales. North American Journal of Fisheries Management 3:176-181.

Hall, D. L. 1991. Age validation and aging methods for stunted Brook Trout. Transactions of the American Fisheries Society 120:644-649.

Harrison, E. J., and W. F. Hadley. 1979. A comparison of the use of cleithra to the use of scales for age and growth studies. Transactions of the American Fisheries Society 108:452-456.

Hoxmeier, R. J. H., D. D. Aday, and D. H. Wahl. 2001. Factors influencing precision of age estimation from scales and otoliths of Bluegills in Illinois reservoirs. North American Journal of Fisheries Management 21:374-380.

Isermann, D. A., J. R. Meerbeek, G. D. Scholten, and D. W. Willis. 2003. Evaluation of three different methods used for Walleye age determination with emphasis on removal and processing time. North American of Journal of Fisheries Management 23:625-631.

Laine, A. O., W. T. Momot, and P. A. Ryan. 1991. Accuracy of using scales and cleithra for aging Northern Pike from an oligotrophic Ontario lake. North American Journal of Fisheries Management 11:220-225.

Logsdon, D. E. 2007. Use of unsectioned dorsal spines for estimating Walleye ages. North American Journal of Fisheries Management 27:1112-1118.

Long, J. M, and W. L. Fisher. 2001. Precision and bias of Largemouth, Smallmouth, and Spotted bass ages estimated with scales, whole otoliths, and sectioned otoliths. North American Journal of Fisheries Management 21:636-645.

Long, J. M., and D. R. Stewart. 2010. Verification of otolith identity used by fisheries scientists for aging Channel Catfish. Transactions of the American Fisheries Society 139:1775-1779.

Maraldo, D. C., and H. R. MacCrimmon. 1979. Comparison of ageing methods and growth rates for Largemouth Bass, *Micropterus salmoides* Lacépède, from northern latitudes. Environmental Biology of Fishes 4:263-271.

McInerny, M. C., and T. K. Cross. 2008. Length at age estimates of Black Crappie and White Crappie among lake classes, reservoirs, impoundments, and rivers in Minnesota. Minnesota Department of Natural Resources Investigational Report 551, St. Paul.

Minnesota Department of Natural Resources (MNDNR). 1993. Manual of instructions for lake survey. Minnesota Department of Natural Resources Special Publication 147, St. Paul

Nash, M. K., and E. R. Irwin. 1999. Use of otoliths versus pectoral spines for aging adult Flathead Catfish. Pages 309-316 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international Ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Niewinski, and C. P. Ferreri. 1999. A comparison of three structures for estimating the age of Yellow Perch. North American Journal of Fisheries Management 19:872-877.

Olson, D. E. 1980. Comparison of marks on scales and dorsal spine sections as indicators of Walleye age. Minnesota Department of Natural Resources Investigational Report 371, St. Paul.

Robillard, S. R. and J. E. Marsden. 1996. Comparison of otolith and scale ages for Yellow Perch from Lake Michigan. Journal of Great Lakes Research 22:429-435.

Ross, J. R., J. D. Crosby, and J. T. Kosa. 2005. Accuracy and precision of age estimation of crappies. North American Journal of Fisheries Management 23:423-428.

Sharp, D., and D. R. Bernard. 1988. Precision of estimated ages of Lake Trout from five calcified structures. North American Journal of Fisheries Management 8:367-372.

Stolarski, J. T., and K. J. Hartman. 2008. An evaluation of the precision of fin ray, otolith, and scale age determinations for Brook Trout. North American Journal of Fisheries Management 28:1790-1795.