Fisheries Management
and Ecology

470-F

Fisheries Management and Ecology, 2008, **15**, 259–271

Emergence of larval yellow perch, *Perca flavescens*, in South Dakota lakes: potential implications for recruitment

D. A. ISERMANN & D. W. WILLIS

Department of Wildlife and Fisheries Sciences, South Dakota State University, Brookings, SD, USA

Abstract Temporal patterns in length frequency distributions and hatch dates were described for larval yellow perch, *Perca flavescens* (Mitchill), captured in surface ichthyoplankton trawls from late April to mid-June 2000 to 2002 in six South Dakota, USA lakes. Fewer than 15 larval yellow perch were collected in four of six lakes during 2002, suggesting that in some cases factors prior to, during or immediately after hatching likely play a critical role in the perch recruitment process. When larval yellow perch were encountered in larger numbers, temporal trends in total length (TL) frequencies indicated that only a single cohort was produced annually in each lake. Most yellow perch in these lakes hatched between 29 April and 17 May, and most hatching occurred during 5–11 days each year. Larval TL was not related to hatch date. The apparent prevalence of relatively short hatch periods in these yellow perch populations probably increases the risk of catastrophic losses resulting from periods of poor environmental conditions.

KEYWORDS: daily rings, hatching, larvae, otoliths, *Perca flavescens,* yellow perch.

Introduction

Yellow perch, *Perca flavescens* (Mitchill), support important recreational fisheries throughout a large portion of North America. Recruitment in populations of yellow perch is often variable (Forney 1971; Henderson 1985; Kallemeyn 1987; Sanderson, Hrabik, Magnuson & Post 1999) and results in inconsistent yellow perch fisheries. This complicates the process of fisheries management, in large part because anglers fail to understand fully perch population dynamics and biologists can often do little to compensate for the effects of recruitment fluctuations on fishery quality. In addition, fluctuations in the abundance of age 0 yellow perch can greatly influence the population dynamics of other economically important species such as walleye *Sander vitreus* (Mitchill) that utilise age 0 perch as prey (Maloney & Johnson 1957; Forney 1974; Meerbeek, Isermann & Willis 2002). Consequently, understanding the mechanisms that regulate yellow perch recruitment remains important to fisheries managers.

Variability in yellow perch recruitment has been linked to abiotic and biotic conditions during the first year of life (Clady 1976; Craig & Kipling 1983; Henderson 1985; Kallemeyn 1987; Anderson, Fisher & Willis 1998; Sanderson *et al*. 1999; Ward, Anderson, Fisher, Isermann, Phelps & Willis 2004). Craig & Kipling (1983) concluded that recruitment of the biologically equivalent Eurasian perch, *Perca fluviatilis* (L.), in Lake Windermere, England was regulated by summer temperature conditions during the first year of life. Similarly, Clady (1976) suggested that temperature and wind conditions regulated early survival of yellow perch in Oneida Lake, New York, USA. However, Sanderson *et al*. (1999) suggested that cycles in the abundance of yellow perch in Crystal Lake, Wisconsin, USA were driven by intra-specific interactions such as cannibalism.

Yellow perch recruitment in South Dakota, USA lakes is typically variable, but recruitment patterns differ substantially among lakes (Lott 1991; Lucchesi 1991; Isermann, Willis, Blackwell & Lucchesi 2007). In some lakes, yellow perch recruitment occurs consistently but at variable levels. Year-class strength fluctuates widely in these systems, but missing or extremely weak year classes are rare (Isermann *et al*. 2007).

Correspondence: D. A. ISERMANN, Minnesota Department of Natural Resources, Section of Fisheries, 1601 Minnesota Drive, Brainerd, MN 56401, USA (e-mail: dan.isermann@dnr.state.mn.us)

doi: 10.1111/j.1365-2400.2008.00610.x

Conversely, some South Dakota yellow perch populations exhibit highly inconsistent recruitment and missing or extremely weak year classes are common (Isermann *et al.* 2007). Research on yellow perch recruitment in South Dakota lakes has offered evidence that year-class strength may be regulated by mechanisms operating early in life (Anderson *et al.* 1998; Ward *et al.* 2004), but, beyond describing relationships between larval perch abundance and climatological conditions (i.e. air temperature, precipitation and wind patterns; Ward *et al.* 2004), these mechanisms have not been thoroughly examined.

Variability in hatch date can influence recruitment in freshwater fishes displaying protracted hatch periods (Rice, Crowder & Holey 1987; Phillips, Jackson & Noble 1995; Cargnelli & Gross 1996; Mion, Stein & Marschall 1998; Pine, Ludsin & DeVries 2000). Variability in the size of age-0 fish has been attributed to hatch timing in several instances (Miller & Storck 1984; Cargnelli & Gross 1996; Pine *et al.* 2000; Walsh, Settle & Peters 2005), suggesting that earlier-hatched individuals experience a survival advantage over later-hatched individuals because of greater size. Smaller individuals hatched later in the season may be more susceptible to predation (Post & Prankevicius 1987; Rice *et al.* 1987) or may lack the energy reserves necessary to survive winter (Oliver, Holeton & Chua 1979; Post & Evans 1989). Conversely, larvae hatching early may encounter relatively poor conditions for growth and survival (Crecco & Savoy 1985; Rice *et al.* 1987; Rutherford & Houde 1995; Pine *et al.* 2000; Garvey, Herra & Leggett 2002). Consequently, protracted hatch periods may maximise survival probabilities by increasing the odds that at least some larvae will encounter satisfactory conditions for growth or survival.

Two previous studies indicated that the duration of yellow perch hatching varies substantially among water bodies, ranging from periods of 9 weeks or more (Fitzgerald, Dale, Thomas & Sale 2001) to periods of less than 20 days (Powles & Warlen 1988). Consequently, hatch duration could be an important factor in the yellow perch recruitment process. Short hatch periods may leave the majority of larval yellow perch vulnerable to episodes of harsh environmental conditions that could result in substantial mortality or, in some instances, the loss of an entire year class; whereas, protracted hatching could result in differential survival among groups (cohorts) of larvae hatching at different times. Both previous studies were conducted over a narrow temporal scale (*viz.*, a single year), precluding examination of annual variation in hatch date and duration, which could in turn influence observed recruitment patterns. Furthermore, previously documented temporal patterns in larval yellow perch length distributions in two South Dakota lakes suggest that yellow perch hatch duration varies both between lakes and between years within the same lake; but in three of four cases, only a single strong cohort of yellow perch larvae was observed annually (Fisher 1996).

To understand the early life history and recruitment process in South Dakota yellow perch populations better, repeated larval sampling was conducted and hatch dates were estimated for larval yellow perch over a 3-year period from six South Dakota lakes exhibiting different recruitment patterns. Yellow perch hatch date and duration were expected to vary among lakes and among years within individual lakes. Based on Fisher (1996) and Powles & Warlen (1988), the following working hypotheses were established: (1) in most years, only a single distinct cohort of larval yellow perch would emerge in each lake; (2) the majority of yellow perch hatching would typically occur during periods of less than 15 days; and (3) total length (TL) of larval yellow perch would be positively related to hatch date.

Materials and methods

Larval yellow perch were collected in surface ichthyoplankton trawls from six glacial lakes in eastern South Dakota, USA (Table 1) during 2000–2002. Lakes were selected to represent two prevailing yellow perch recruitment patterns observed in South Dakota lakes (Lott 1991; Lucchesi 1991; Isermann *et al.* 2007). Yellow perch populations in East 81 Slough, Enemy Swim and Pickerel lakes exhibit relatively consistent recruitment patterns (measured as age-2 catch in annual summer gill-net surveys; Isermann *et al.* 2007), and yellow perch populations in Madison, Sinai

Table 1. Surface area, mean depth, trophic status and number of surface ichthyoplankton trawls used on each sampling date to collect larval yellow perch from six eastern South Dakota lakes during 2000–2002

Lake	Area (ha)	Mean depth (m)	Trophic state*	Larval trawls
East 81	440	5.0	Eutrophic	10
Enemy Swim	884	4.8	Mesotrophic	12
Madison	1145	2.7	Eutrophic	16
Pickerel	386	6.1	Mesotrophic	10
Sinai	697	5.2	Eutrophic	10
Waubay	6293	4.9	Eutrophic	20

*Based on Carlson's (1977) trophic state index.

and Waubay lakes exhibit highly variable recruitment patterns (Isermann *et al.* 2007).

Larvae were collected from each lake at 7- to 15-day intervals between 28 April and 18 June using a 1000-μm mesh (bar measure) conical ichthyoplankton net that was towed immediately below the surface during daylight hours. Sampling sites on each lake were initially randomly selected and then remained fixed for the duration of the study. The number of tow sites per lake varied based on lake surface area (Table 1) and were equally distributed between offshore (≥100 m from shore) and nearshore (within 100 m of shore) strata to account for potential migrational patterns of yellow perch larvae (Post & McQueen 1988). The amount of water filtered during each tow was estimated using a flowmeter (General Oceanics® model 2030R) mounted in the centre of the net frame. Water depths at selected sampling sites generally reflected the range of depths present in each lake, but sampling in water depths of less than 1.5 m was not possible. Surface water temperatures were recorded at a single site on each lake on most sampling dates.

Larval yellow perch sampling was conducted during this time period based on previous work demonstrating that yellow perch typically spawn in South Dakota lakes and wetlands from mid-April to mid-May at water temperatures less than 17 °C (Fisher 1996; Hanchin 2001; Mangan 2004). On Lake Madison during 2000 and 2001, egg deposition on submerged conifer bundles occurred over 3–15 days periods from 21 April to 5 May at water temperatures between 7 and 17 °C, and no new egg deposition was observed after the first week of May (Hanchin 2001). Assuming that egg deposition was complete by mid-May of each year, larval sampling in this study should have encompassed the entire period larval yellow hatching occurred in these lakes based on incubation rates observed at water temperatures greater than 12 °C (Mansueti 1964; Hale & Carlson 1972; Hokanson & Kleiner 1974; Powles & Warlen 1988).

Larval fish samples were initially fixed in 10% formalin on most sampling dates and then stored in 90% ethanol. Larvae were identified to species using the keys provided in Auer (1982). For each trawl, larval yellow perch densities were calculated based on the volume of water filtered; larval densities were subsequently standardised to the number of larvae per 100 m^3 of water filtered. Median values (i.e., median density across trawl samples) were used to describe larval yellow perch density on individual sampling dates. For each sampling date on each lake, up to 300 yellow perch larvae were randomly selected from preserved samples and TL was measured to the nearest millimetre. Specimen shrinkage was accounted for by adding 1.25 mm to TL (Fisher, Anderson & Willis 1998).

To obtain otoliths for estimating hatch dates, larval samples collected on a single sampling date during the first 12 days of June were immediately stored in 90% ethanol to prevent otolith degradation resulting from exposure to formalin (Essig & Cole 1986). Larval samples from this time period were used to estimate hatch date for several reasons. Based on previous investigations on yellow perch spawning and hatching in South Dakota lakes (Fisher 1996), it was assumed that most yellow perch hatched by 1 June; hence, if multiple cohorts of larval perch emerged each year they should be present in samples collected during this period, unless a cohort hatched but did not survive until June. This possible exception would have been apparent from previous sampling. Additionally, previous analyses of yellow perch otoliths (Powles & Warlen 1988) validated daily ring counts for up to 35 days post-hatching; hence, the date of otolith sampling was selected in an attempt to capture yellow perch prior to reaching 35 days post-hatch. Sampling dates in the first half of June were also selected to avoid problems with ontogenetic changes in the behaviour of age-0 yellow perch. Previous work in temperate lakes suggests that age-0 yellow perch move to littoral habitats or become demersal at approximately 25 mm total length (Forney 1971; Post & McQueen 1988; Post, Rudstam & Schael 1995), making them less vulnerable to capture in surface trawls. Previous larval sampling on South Dakota lakes suggested that some larval yellow perch attained total lengths of 25 mm or more in mid-June (Fisher 1996).

Following storage periods of up to 6 weeks, lengths were recorded and sagittal otoliths were extracted from a maximum of 50 randomly selected yellow perch larvae. Hatch dates were not estimated in lake-year cases when fewer than 25 yellow perch larvae were collected on a designated otolith sampling date. Only 30 larvae were selected for otolith analysis due to the short range of larval TL (range = 3 mm) collected on the otolith sampling date in Pickerel Lake in 2002. One otolith per fish was mounted on a glass slide and viewed at 400 × magnification; immersion oil was used to improve clarity, and images were projected on a television monitor. Daily rings on each otolith were counted three times by one reader, and the mean of the three counts (C) was used in estimating hatch dates. Only a single reader enumerated daily rings based on an *a priori* assessment of between-reader precision, which indicated that the precision between two readers analysing 100 otoliths was relatively high (mean CV in average reader count = 5.1) and that the mean difference between average reader counts was not significantly different from 0 (paired *t*-test, $t = 0.38$, d.f. = 99, $P = 0.70$).

Hatch dates (H_D) were initially estimated by subtracting C from day of capture (D_C; 1 January = day 1). Powles & Warlen (1988) examined sagittal otoliths from larval yellow perch hatched from eggs in the laboratory at three different incubation temperatures. Initial growth increments were visible 1 day after hatching on at least 50% of all larval otoliths examined, and the mean number of daily rings observed was on an average 1 day less than the actual number of days post-hatch for larval perch examined up to 12 days after hatching. Consequently, estimates of H_D were systematically corrected by adding 1 day to C:

$$H\hat{D} = H\hat{C} - (C + 1).$$

Simple linear regressions were used to assess the relationship between TL of larval yellow perch at the time of otolith removal and H_D under the assumption that potential relationships would be approximately linear during the first 40 days of life. Post & Prankevicius (1987) indicated that yellow perch growth was linear over the first 40 days of life, and a similar trend has been reported for several other species (Phillips *et al.* 1995; Pine *et al.* 2000; Garvey *et al.* 2002; Walsh *et al.* 2005).

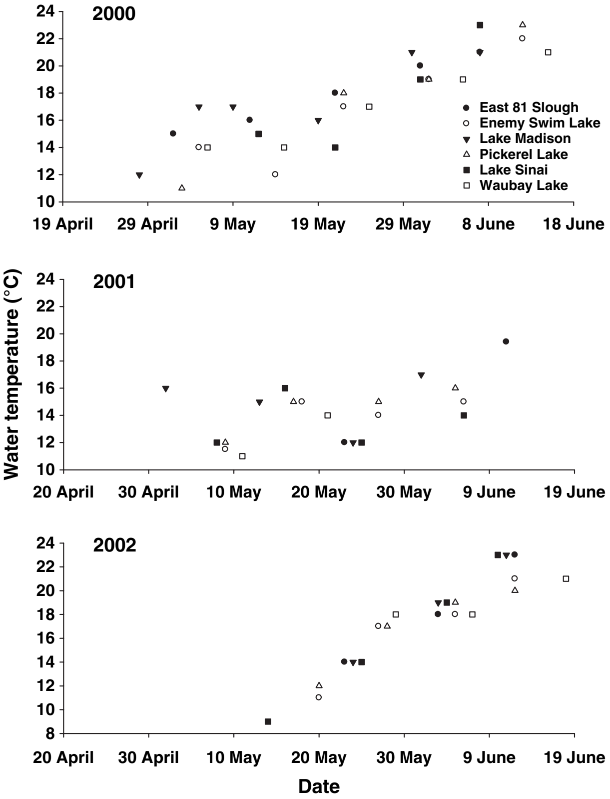

Figure 1. Surface water temperatures measured at a single site on dates when surface ichthyoplankton trawls were conducted on six South Dakota lakes. Temperatures were not recorded on all sampling dates.

Results

Over the 3-year sampling period, 1172 larval trawls were completed on the six study lakes; mean towing duration was 4.2 min (SE = 1.99), mean towing speed was 1.36 m/s (SE = 0.009) and mean volume filtered was 153.8 m^3 (SE = 1.58). Weather and wave conditions prevented collection of 34 samples, 32 of which occurred on Waubay Lake, the lake with the largest surface area. Samples were missed on 6 of the 15 total sampling dates on Waubay Lake; on 4 of the 6 sampling dates, 4 or fewer of the 20 samples could not be collected and 9 and 12 of the 20 samples could not be collected on the remaining two dates.

Surface water temperatures measured during larval sampling were generally < 16 °C during the first 2 weeks of May (range = 9–17 °C) and typically > 18 °C during the first 2 weeks of June (range = 14–23 °C; Fig. 1). Five or fewer yellow perch larvae were collected in most of the initial trawl samples (Fig. 2). Larval yellow perch typically were first collected between 9 May and 21 May in the six study lakes in 2000 and 2001; yellow perch larvae were captured prior to 9 May only on East 81 Slough in 2000. During 2002, > 15 yellow perch were captured only in Enemy Swim and Pickerel lakes; yellow perch larvae were not initially captured until 5 June in these two lakes. Peak larval densities and the date on which peak larval density was observed varied among lakes and among years within lakes (Fig. 3). Peak larval yellow perch densities generally occurred during late May or early June when surface water temperatures were 12–19 °C. In some instances, few or no larval yellow perch were collected during an entire sampling season. In 2002, < 15 yellow perch larvae were collected in all samples on East 81 Slough, Lake Madison and Sinai Lake and no yellow perch were encountered on Waubay Lake. Peak larval densities were also relatively low in Sinai and Waubay lakes during 2000.

Distributions of larval TL were generally unimodal (Fig. 2), suggesting that most of the larval perch in these lakes emerged as a single cohort. The TL of larval yellow perch ranged from 4 to 11 mm on the initial dates of capture. With the exception of Enemy

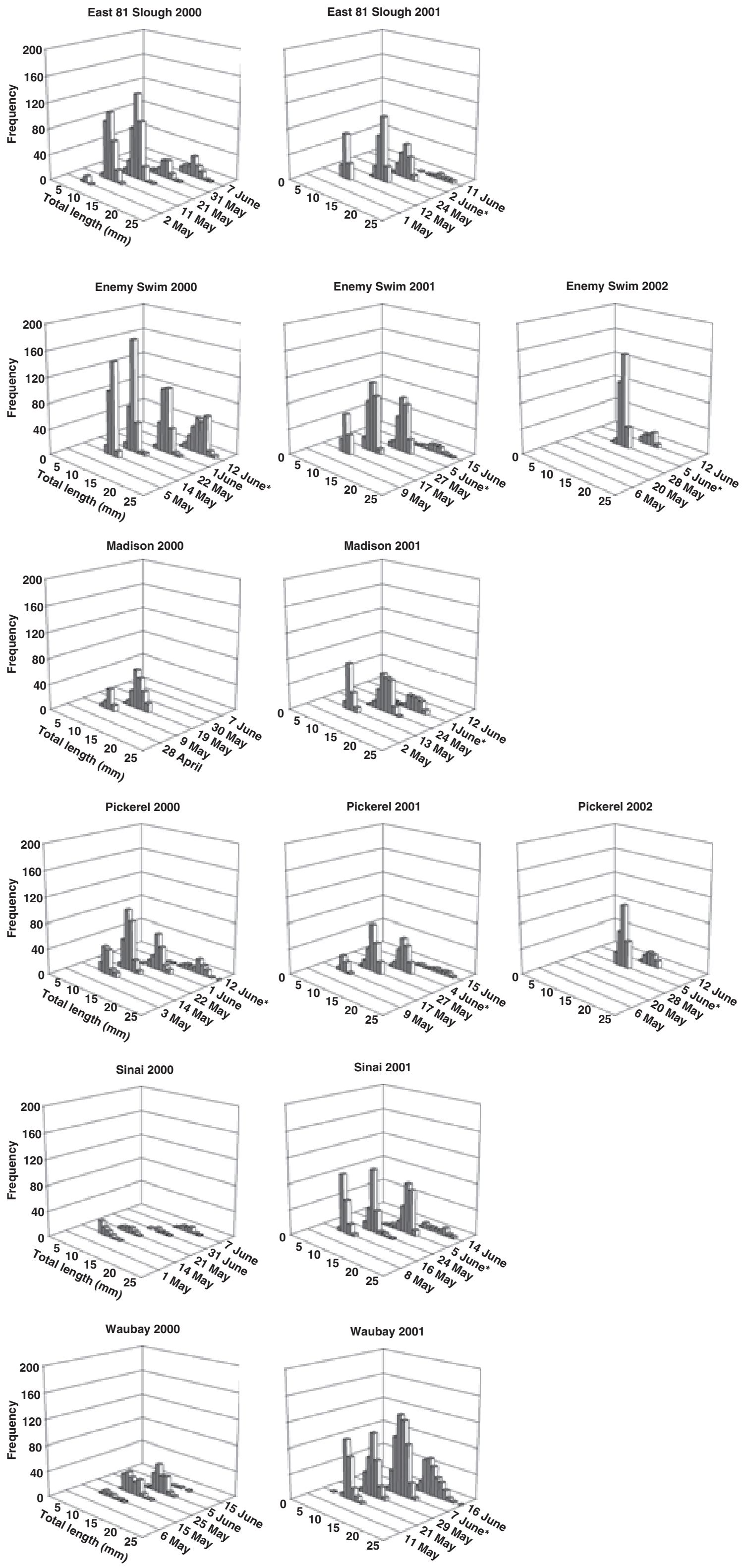

Figure 2. Length frequencies of larval yellow perch collected in surface trawls from six South Dakota lakes, 2000–2002. Larvae were collected in surface trawls conducted from late April to mid-June. Sampling dates without total length distributions represent dates where five or fewer yellow perch larvae were collected. Asterisks denote sampling dates in June when otoliths were removed for hatch date estimation.

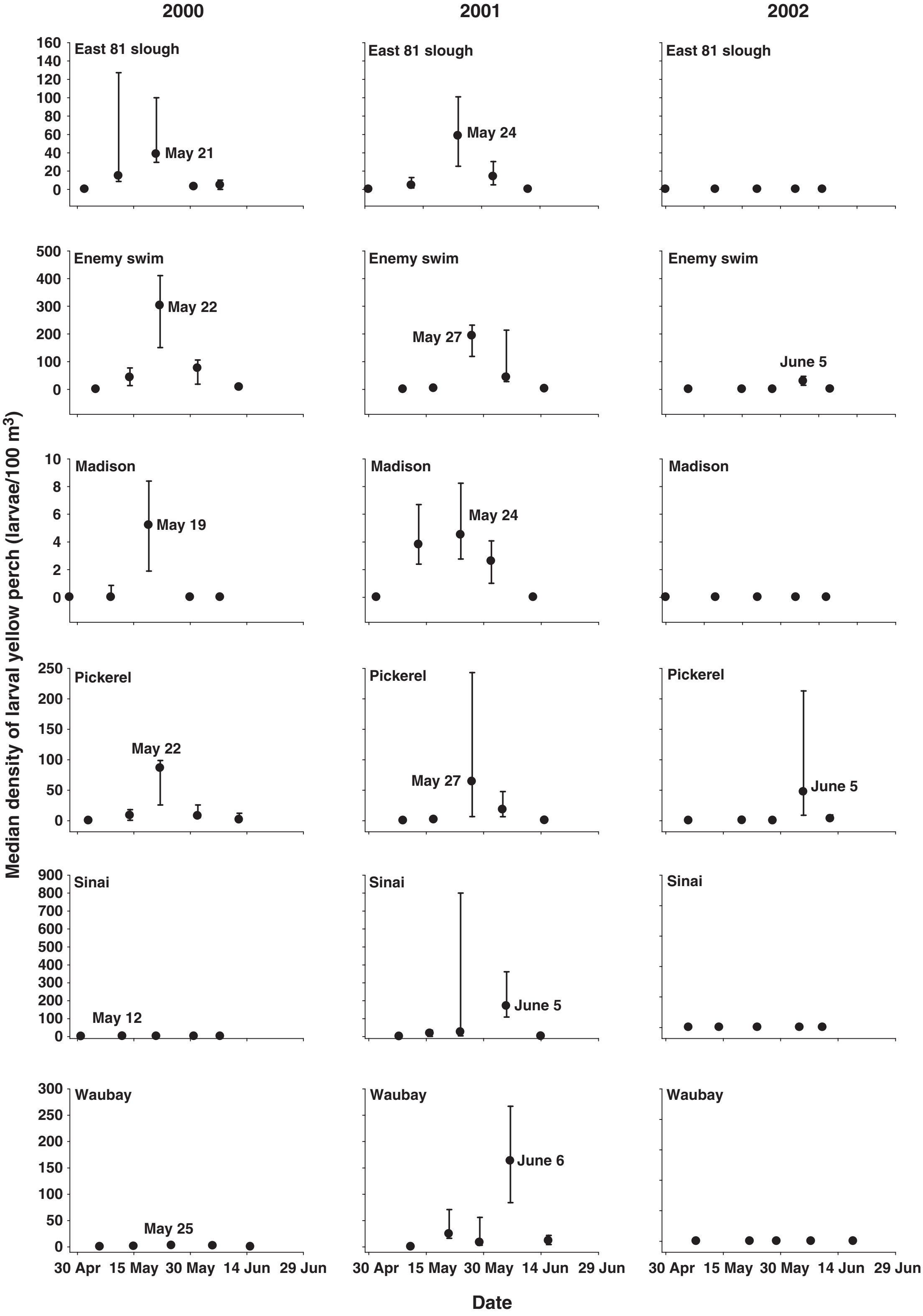

Figure 3. Median larval yellow perch densities and 95% confidence intervals estimated from surface ichthyoplankton trawls conducted on six South Dakota lakes during 2000–2002. Calendar date on each panel is the sampling date when peak median larval yellow perch density was observed. Insufficient fish were collected from East 81 Slough and Madison, Sinai and Waubay lakes in 2002 to determine a date of peak density.

Swim and Pickerel lakes in 2002, where yellow perch larvae were not initially encountered until 5 June, perch < 10 mm were rare in June samples, suggesting that yellow perch hatching was no longer occurring. Similarly, no yellow perch larvae < 11 mm TL were collected on 12 June in Enemy Swim and Pickerel lakes in 2002.

Yellow perch hatch dates were estimated for 10 of the possible 18 lake-year cases. Hatch dates were not estimated for Madison, Waubay and Sinai lakes in 2000 and 2002 and in East 81 Slough in 2002 because insufficient numbers of larval yellow perch were encountered on scheduled otolith sampling dates in June. Larval samples collected in 2000 from East 81 Slough were incorrectly stored in 10% formalin for several weeks, rendering otoliths unreadable.

Based on lake-year samples when sufficient fish were collected for hatch-date analysis, the majority of yellow perch hatched from 29 April through 17 May. Hatch durations were short, ranging from 5 to 11 days (median = 7 days, Fig. 4). Median hatch dates among individual lake-year samples ranged from 5 May to 14 May. With one exception, TL of larval yellow perch was not linearly related to hatch date for the TL range of larval perch selected for otolith removal (Fig. 5). Hatch date accounted for a significant amount of the variation in TL in Pickerel Lake in 2001, but the coefficient of determination ($r^2 = 0.27$) was relatively low.

Discussion

Few larval yellow perch were collected during the entire larval sampling season in some lakes in some years, indicating that mechanisms prior to, during or immediately following hatching may play a critical role in regulating year-class strength. Similar conclusions have been reached in previous studies on yellow perch recruitment (Clady 1976; Henderson 1985; Kallemeyn 1987; Newsome & Aalto 1987; Anderson *et al.* 1998). In 2002, the low numbers of larvae collected in four of the six lakes and the absence of larvae prior to June in Enemy Swim and Pickerel lakes may have been related to cold water temperatures. The three water temperatures recorded between 10 May and 20 May 2002 did not exceed 12 °C, whereas water temperatures at the same time period during the previous 2 years exceeded 12 °C in all but one instance (Fig. 1). Ward *et al.* (2004) reported that relationships between larval yellow perch abundance and May water temperatures in these six lakes were generally positive but statistically significant in only two of the six lakes. Hokanson & Kleiner (1974) demonstrated that the percentage of yellow perch eggs resulting in swim-up larvae (< 30%) was substantially lower at temperatures less than 10 °C than at temperatures between 10 and 20 °C, where more than 50% of perch eggs typically resulted in swim-up larvae. Furthermore, Clady (1976) reported that exposure of yellow perch prolarvae to water temperatures between 11 and 14 °C adversely affected survival in Oneida Lake, New York. Interestingly, median hatch dates for yellow perch larvae in Enemy Swim and Pickerel lakes in 2002 were similar to or slightly earlier than median dates observed in 2000 and 2001, suggesting that spawning and hatching may not have been delayed but that cold water temperatures following hatching may have reduced larval growth and delayed recruitment to the larval trawl.

Temporal trends in total length distributions and hatch durations indicate that most larval yellow perch in these South Dakota lakes emerge as single cohorts. This also suggests that yellow perch spawning occurred during a relatively brief time period, which reflects previous observations on perch spawning behaviour in South Dakota lakes (Fisher 1996; Hanchin 2001; Mangan 2004). Brief spawning or hatch periods have been reported for many yellow perch populations. Weber & Les (1982) reported that yellow perch in Lake Winnebago, Wisconsin, USA usually spawned over periods of 11 days or less (range = 7–22 days), and Post *et al.* (1995) asserted that yellow perch spawning in Lake Mendota, Wisconsin, USA was synchronous based on length distributions of age-0 yellow perch captured in purse seines. Powles & Warlen (1988) estimated that yellow perch in four Ontario lakes hatched over periods of 18 days or less (range = 6–18 days), and Clady (1976) concluded that perch hatching in Oneida Lake was largely completed during a 2-week period. Conversely, Fitzgerald *et al.* (2001) estimated that yellow perch in Lakes St Clair and Opinicon, Ontario hatched over periods greater than 9 weeks.

The factors regulating the duration of yellow perch spawning and hatching are unclear at this time, but differences in thermal heterogeneity among lakes seem a likely source of variation. In a large, complex lake system such as Lake St Clair (110,000 ha), yellow perch spawn and hatch in a variety of locations exhibiting a diversity of thermal regimes, increasing the probability of protracted spawning and hatch periods, as documented by Fitzgerald *et al.* (2001). However, Fitzgerald *et al.* (2001) also reported protracted yellow perch hatching (> 9 weeks) in Lake Opinicon, a 900-ha lake in Ontario that had a mean depth similar to several of the South Dakota lakes used in the current study. Possibly, the extended hatch period observed for yellow perch in Lake Opinicon was related to lake

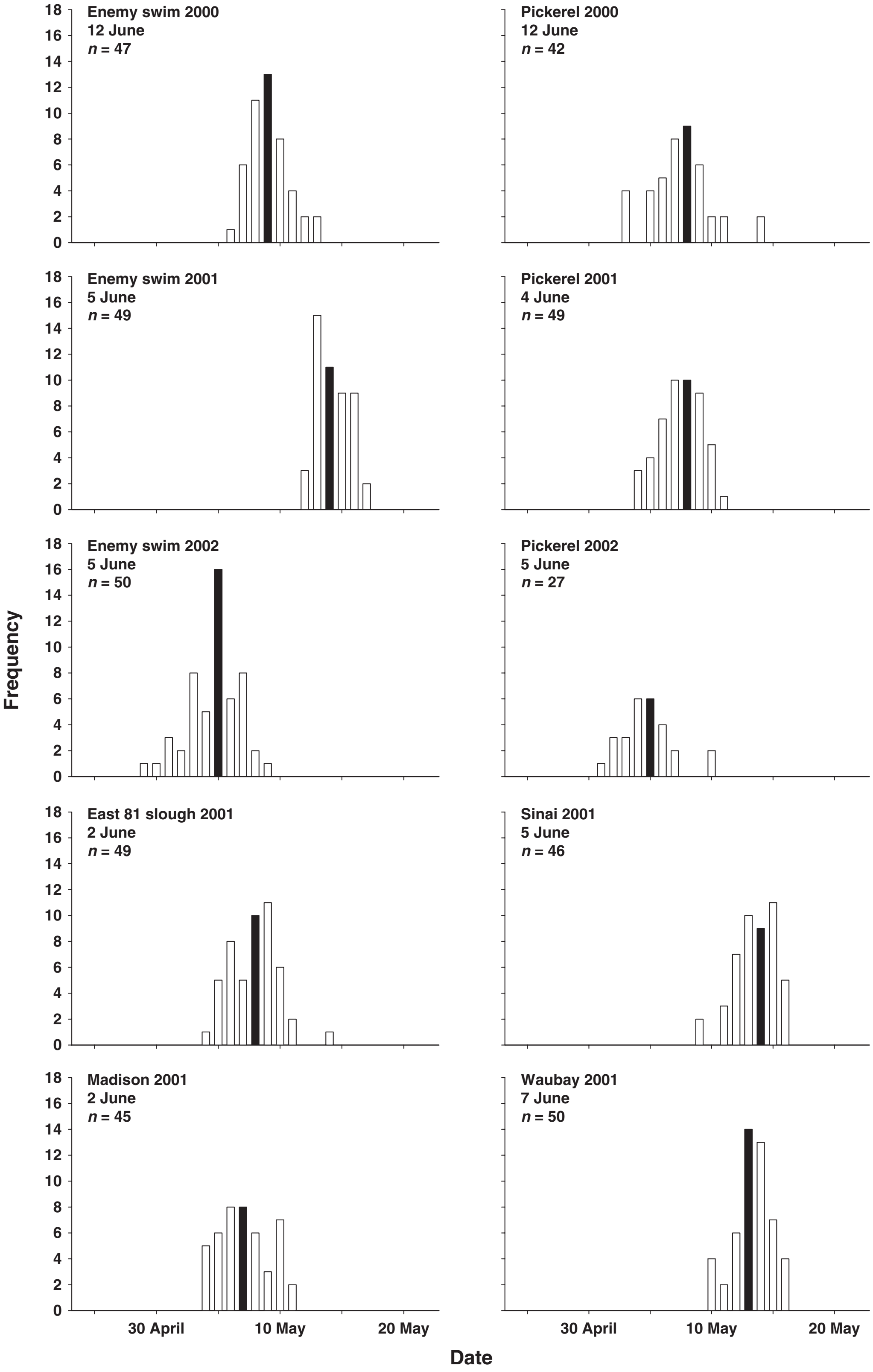

Figure 4. Distribution of hatch date for larval yellow perch collected from South Dakota lakes, June 2000–2002. Sampling dates when otoliths were removed and the number of otoliths examined (*n*) is reported. Black bar indicates median hatch date.

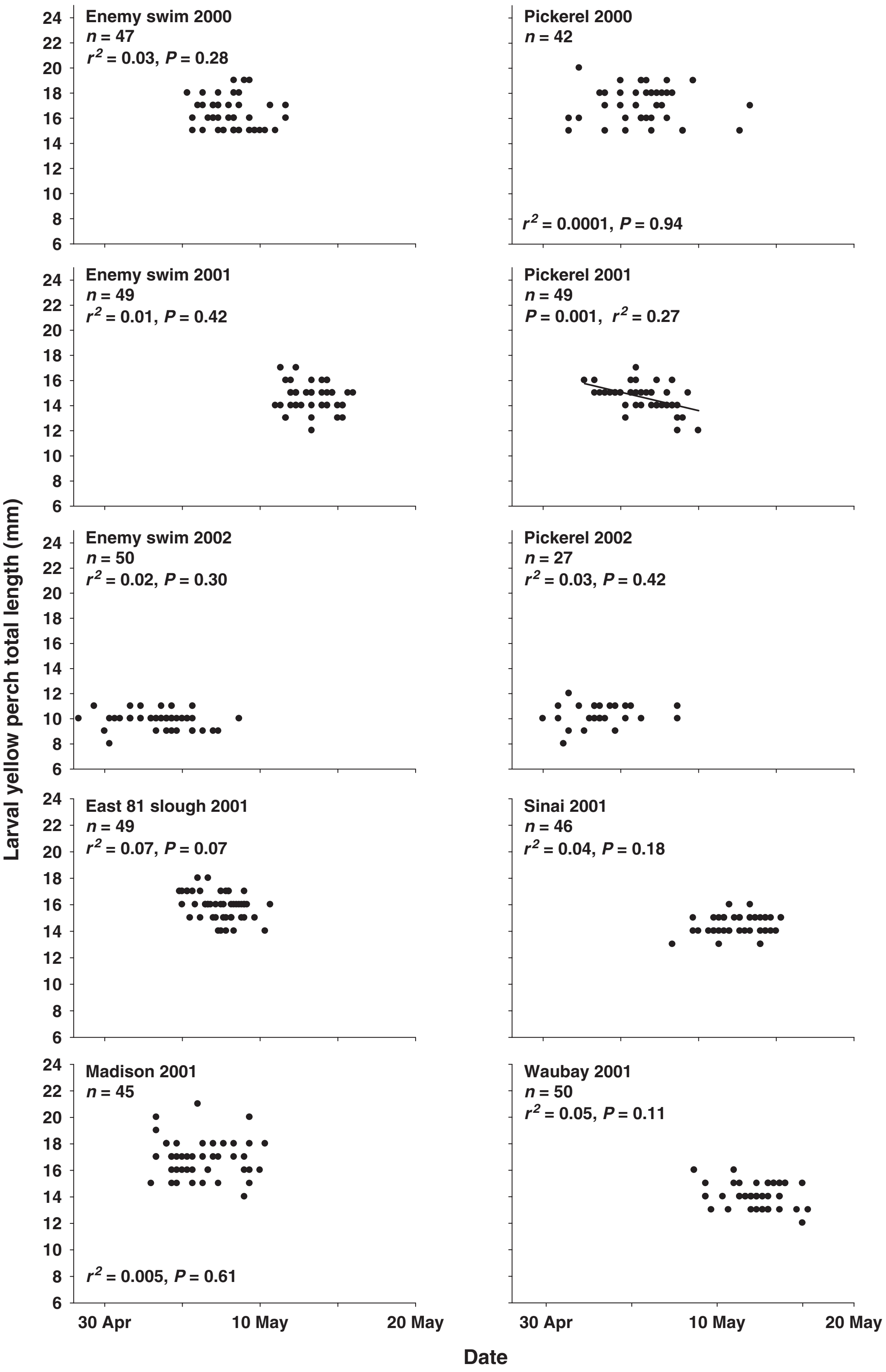

Figure 5. Larval total length in relation to hatch date for larval yellow perch collected from six South Dakota lakes during 2000–2002.

morphology; Lake Opinicon is relatively dendritic and likely provides a more diverse array of habitats and, consequently, a greater degree of thermal variation than most South Dakota lakes. Powles & Warlen (1988) did not report the size of the Ontario lakes used in their study of yellow perch hatch dates, but they observed the shortest yellow perch hatch duration in the shallowest lake used in their study, while the longest duration was observed in Clear Lake, the lake exhibiting the steepest littoral zone. They postulated that yellow perch egg deposition at different depths would result in different incubation temperatures and consequently a wider range of hatch dates. Similarly, Huff, Grad & Williamson (2004) reported that incubation rates of yellow perch eggs varied with depth in two small (< 50 ha) Pennsylvania, USA lakes because of thermal stratification.

The degree of thermal heterogeneity occurring in South Dakota lakes during yellow perch spawning and hatching was not investigated during this study. However, these lakes are dimictic and thermal stratification at the time of yellow perch spawning and hatching would be unlikely, contributing to the observed narrow range of hatch dates. Furthermore, most of the lakes can be characterised as having relatively open, windswept basins of limited complexity that likely promote wind-driven mixing that might delay or limit thermal stratification. Regardless of thermal stratification, if the majority of female yellow perch consistently select littoral areas that are uniform in terms of thermal regime for egg deposition (Fisher 1996; Huff *et al.* 2004), short hatch periods would be more likely to occur. Certain portions of each lake (e.g. protected bays or coves) may have warmed faster than areas associated with the main basin; but larval sampling sites encompassed a wide range of habitats, and prevailing wind patterns likely promoted mixing of larvae hatching in multiple areas of the lake. This suggests that these potential differences in warming rate were not sufficient to elicit extended spawning and hatching periods.

From a practical standpoint, attempting to describe hatch duration for a species over multiple lakes and years is logistically challenging. Ideally, otoliths might have been collected from every larval sampling period to improve the likelihood that all yellow perch hatching within a given season were accounted for, but this approach was not possible because of the time and cost associated with processing otoliths. Some yellow perch larvae may have hatched and not survived until otoliths were collected in June, but temporal trends in larval length frequencies suggest that no major larval cohorts were excluded from otolith analyses. Additionally, by June, some larger yellow perch may have no longer been susceptible to capture in the surface trawls because of shifts in behaviour that may occur as perch attain TL ≥25 mm (Forney 1971; Post & McQueen 1988; Post *et al.* 1995), but Fisher (1996) demonstrated that at least some perch > 25 mm TL were captured in surface trawls conducted on Pelican Lake, South Dakota. In 8 of 10 instances, no yellow perch larvae exceeding 20 mm TL were encountered on or before otolith sampling dates. In Enemy Swim and Pickerel lakes in 2000, otolith samples were not collected until 12 June when 25 larval yellow perch between 20 and 24 mm TL were captured on the two lakes, accounting for between 5 and 15% of all larvae encountered; however, only one of these larvae exceeded 22 mm TL. This suggests that few yellow perch larvae had attained 25 mm TL at the time otolith samples were collected.

Random selection of fish has been previously used to estimate ages or hatch dates from otolith microstructure (e.g., Sammons, Dorsey, Bettoli & Fiss 1999; Fitzgerald *et al.* 2001; Walsh *et al.* 2005; Smith, Sullivan & Rudstam 2006), but this may not be the most accurate approach for estimating the full range of hatch dates, as rarer fish within the distribution may not be selected. The random sample of 30–50 fish selected for otolith analysis was insufficient to capture the entire range of total lengths observed on specified sampling dates, but in 5 of 10 cases random otolith samples accounted for 91–100% of all larval yellow perch total lengths observed on a selected otolith sampling date; in the remaining five samples, fish selected for otolith removal accounted for 73–88% of all observed total lengths. Furthermore, our analyses suggested that larval TL was not a useful surrogate for hatch date.

Relationships between hatch date and total length of yellow perch larvae were not readily apparent, possibly because the majority of yellow perch hatched over a relatively short period of time. Generally, strong relationships between hatch or swim-up date and TL attained by age-0 fish have been noted when hatch or swim-up occurred during periods of 30 days or more (e.g. Miller & Storck 1984; Cargnelli & Gross 1996; Ludsin & DeVries 1997; Garvey *et al.* 2002). When yellow perch hatch over a wide range of dates (i.e., Fitzgerald *et al.* 2001), hatch date likely exerts a stronger influence on the growth rates and ultimate size attained by age-0 yellow perch than when most perch hatch over a relatively narrow time period and encounter similar environmental conditions.

Yellow perch populations exhibiting relatively brief spawning strategies are vulnerable to production of weak or failed year classes. Wind and thermal conditions during yellow perch spawning, incubation or hatch periods have been implicated as important factors regulating hatch rate (Hokanson & Kleiner 1974), larval survival and abundance (Clady 1976; Ward *et al.* 2004), and subsequent recruitment to various life-history stages (Clady 1976; Eshenroder 1977; Kallemeyn 1987; Newsome & Aalto 1987; Ward *et al.* 2004). High winds can dislodge egg masses (Clady 1976) or result in thermal shock because of water movements (Newsome & Aalto 1987), and low temperatures may result in low hatch rates (Hokanson & Kleiner 1974) and reduced larval survival (Clady 1976). Ward *et al.* (2004) reported that larval perch abundance in these six South Dakota lakes was generally related to weather patterns observed during March through May of each year and that larval abundance tended to be higher in years with less wind, more precipitation and warmer air temperatures. Predation (Forney 1971; Brandt, Mason, MacNeil, Coates & Gannon 1987; Sanderson *et al.* 1999) and forage availability (Dettmers, Raffenberg & Weis 2003; Graeb, Dettmers, Wahl & Cáceres 2004) can also affect larval survival and could influence year-class strength. Consequently, some missing or weak year classes may be attributed to egg loss or poor hatch success, while others may result from mortality incurred at the larval stage.

While relatively short spawning and hatch periods may be typical for yellow perch in South Dakota lakes, this may not always occur. A relatively wide TL range (9–30 mm) of yellow perch larvae was observed in surface ichthyoplankton trawls conducted by Fisher (1996) in Pelican Lake, South Dakota on 19 June 1995, suggesting a more protracted hatch duration than observed in the current study. Additionally, based on yellow perch egg deposition occurring on submerged conifer trees, yellow perch spawning in one South Dakota wetland occurred over a 23-day period (Mangan 2004). Protracted spawning or hatching of yellow perch may represent a response to variable environmental conditions (Weber & Les 1982) and could enhance the potential that some yellow perch larvae will encounter suitable conditions for survival and growth. Consequently, future research assessing the relationships between spawning and hatch durations, prevailing environmental conditions and year-class strength may offer new insights regarding factors regulating yellow perch recruitment.

Acknowledgments

Thanks are extended to the numerous personnel at South Dakota State University and the South Dakota Department of Game, Fish and Parks (SDGFP) who assisted with this project. This manuscript was greatly improved by comments from three anonymous reviewers. Funding for this research was provided by SDGFP through Federal Aid in Sportfish Restoration funds (Federal Aid Project F-15-R, Study 1584).

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