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Estimating Predation on Declining River Herring: Tag-recapture Study of Striped Bass in the Connecticut River

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Executive Summary

Purposes of the Project

- Populations of anadromous alewife *Alosa pseudoharengus* and blueback herring *Alosa aestivalis*, collectively referred to as river herring, have declined in the Connecticut River. The number of blueback herring passing Holyoke Dam, the most downstream dam on the mainstem Connecticut River, has declined from 630,000 in 1985 to a recent low of 21 in 2006.
- A hypothesis for why river herring have declined in the Connecticut River is that predation pressures have increased associated with recent increases in abundance of striped bass *Morone saxatilis*. Information on striped bass abundance, size structure, and consumption rates are required to test this hypothesis. This study was designed to provide estimates of striped bass population size in the Connecticut River during the spring migration season.

Objectives

- Conduct an intensive mark-recapture exercise in the Windsor Locks section of the Connecticut River to estimate absolute abundance of striped bass within this area at weekly intervals using either an open or robust mark-recapture model.
- Calibrate weekly estimates of relative abundance (electrofishing CPH) obtained in the Windsor Locks section to weekly absolute abundance estimates.
- Use this calibration to estimate absolute abundance from relative abundance in the four other river sections sampled during SWG Project sampling.
- Use these five estimates of absolute abundance to extrapolate population size estimates at weekly intervals for the entire river stretch from Wethersfield CT to Holyoke MA.
- Use individual capture histories compiled during the intensive mark-recapture exercise to estimate absolute abundance of striped bass in Windsor Locks during May-June using maximum-likelihood closed population models.
- Use all tag recaptures (electrofishing and angler) and creel survey data to estimate absolute abundance of striped bass in the river stretch from Wethersfield CT to Holyoke, MA during May-June using a Schnabel mark-recapture model.

Methods

- Striped bass were sampled between Wethersfield, CT and Holyoke, MA in May-June 2007 and 2008 by night-time boat electrofishing.
- Two mark-recapture approaches were used to estimate striped bass population size. The primary approach involved intensive boat electrofishing within a small area of the study region (Windsor Locks) and application of open, closed, or robust mark-recapture models fit using maximum likelihood techniques. These approaches relied solely on recaptures made during electrofishing. The secondary approach incorporated both angler and electrofishing recaptures in a Schnabel closed population model. The Schnabel model required creel survey data to provide daily estimates of angler catch.
- All striped bass captured during electrofishing were measured (TL, mm) and enumerated. All fish $\geq$ 300 mm TL were tagged with a uniquely-coded internal anchor FLOY tag.
- Reports of tagged striped bass were solicited from recreational anglers. Monetary rewards were offered for tag reports. A high-reward tag was used in conjunction with standard tags in 2008 to allow estimation of standard tag reporting rate. The tagging

program was advertised via posters at fishing locations, letters to tackle shop owners, and postings on local internet fishing forums.

- Connecticut Department of Environmental Protection (CDEP) conducted a creel survey of the Connecticut River in 2008. The survey covered the river stretch from Middletown, CT to the CT/MA border and provided estimates of angler catch of striped bass during the open-water season (March – October).

Key Findings

- Electrofishing operations in both years began in early May and were discontinued by mid-June. Sampling effort was significantly higher in 2007 than in 2008 (42 sample nights vs. 14 sample nights). A variety of sites within the study region were sampled in 2007; sampling was restricted to Windsor Locks in 2008.
- A total of 662 striped bass was tagged in 2007, the majority in Windsor Locks. Anglers reported 34 tag recaptures and an additional 7 recaptures were made during electrofishing operations. Of the 41 tag recaptures made in 2007, 18 were made within the study region during the study season (May-June) and were therefore useful for population size estimation.
- A total of 535 striped bass was tagged in 2008. Anglers reported 23 tag recaptures, and an additional 3 recaptures were made during electrofishing operations. Of the 26 tag recaptures made in 2008, 17 were made within the study region during the study season (May-June) and were therefore useful for population size estimation. Based on high-reward tag reporting rates, standard tag reporting rate was estimated as 68%.
- Electrofishing recapture rates were insufficient to fit open, closed, or robust population models using maximum likelihood estimation in either year.
- Population size was estimated in 2008 using a Schnabel mark-recapture model; 56,207 (95% CI = 36,737 – 89,931) striped bass ≥ 300 mm TL were in the Connecticut River between Hartford and the MA/CT border during May 2008. Estimates were unavailable for 2007 because CDEP did not conduct a creel survey in that year.

Conclusions

- The Schnabel model population size estimate is biased to an unknown degree due to violation of underlying assumptions of the model. However, this population size estimate will still serve as a valuable reference point for quantifying predation in the Connecticut River.
- Future efforts to apply an open population model will require a much more extensive tagging and recapture effort. Alternately, telemetry studies of striped bass movement could elucidate the magnitude and direction of bias in closed population model estimates.

Recommendations

- Conduct further work to elucidate the magnitude and direction of bias in closed population model estimates. Such studies could incorporate telemetry to quantify movement rates and capture probabilities.
- Consider executing a larger-scale mark-recapture effort that will obtain recapture rates high enough to permit population size estimation with more appropriate statistical models.

- Use estimates of striped bass population size, in conjunction with data on striped bass size structure and consumption rates, to estimate population-level consumption of herring prey by striped bass in the upper Connecticut River during the spring migration season.

Introduction

Striped bass (*Morone saxatilis*) is an economically-important finfish native to the Atlantic coast of North America, from the St. Lawrence to northern Florida, and along the northern shore of the Gulf of Mexico (Collette and Klein-MacPhee 2002). The fish is highly prized for food and sport. Commercial landings of the species peaked at almost 15 million pounds in 1973 and then declined by more than 75% over the next decade (Atlantic States Fishery Management Council 1999). Following imposition of strict limits on commercial and recreational fishers, the stock was declared fully recovered by the Atlantic States Marine Fisheries Commission in 1995; landings have continued to climb since then. Striped bass populations in the Atlantic coastal region reached historic peaks of abundance in the late 1990's before declining slightly over the next decade (NMFS 2008). Adult striped bass are large, generalist predators capable of extended feeding forays into freshwater (Collette and Klein-MacPhee 2002; Savoy and Crecco 2004); their prodigious recovery has therefore created concerns about potential ecological impacts (Hartman 2003; Walter et al. 2003).

River herring, a term collectively applied to the closely-related anadromous alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*), have been a primary focus of concerns about ecological impacts of striped bass recovery (Hartman 2003; Savoy and Crecco 2004). Anadromous alewife and blueback herring have a largely sympatric distribution along the Atlantic coast of North America, from the maritime provinces of Canada to the southeastern US (Mullen et al. 1986). Adults inhabit relatively shallow (<100m) waters along the continental shelf (Neves 1981). The timing of return to freshwater spawning habitats in spring varies with species and is cued by temperature (Kissil 1974; Loesch 1987). Juvenile river herring complete a period of freshwater residence before migrating to estuarine or marine environments during the period of June –November (Loesch 1987). During periods of freshwater and estuarine residence, both adult and juvenile river herring provide forage for numerous aquatic, terrestrial, and avian predators (Loesch 1987).

River herring populations have declined coast-wide in recent decades, particularly in southern New England (Davis and Schultz 2009). Indicative of this trend is the decline of blueback herring in the Connecticut River. The number of blueback herring passing Holyoke Dam, the most downstream dam on the mainstem Connecticut River, has declined from 630,000 in 1985 to a recent low of 21 in 2006 (USFWS 2008). In response to evidence of wide-spread

declines, the Connecticut Department of Environmental Protection (CDEP) enacted an emergency closure of its river herring fishery in 2002. Similar closures were instituted in the neighboring states of Massachusetts and Rhode Island in 2005. The closures apply to both coastal and ocean-intercept fisheries, and therefore constitute a moratorium on directed fisheries for river herring in southern New England.

One potential cause of river herring declines in the Connecticut River is the increasing prevalence of adult striped bass in the river during spring months (Savoy and Crecco 2004). Striped bass are known to prey on river herring (Walter et al. 2003), and the temporal overlap of these species' migration into the Connecticut River suggests a causal relationship (Savoy and Crecco 2004). However, more detailed data on striped bass abundance, spatiotemporal distribution, size structure, and prey use within the Connecticut River are needed for a full assessment of the role striped bass predation has played in river herring declines (Savoy and Crecco 2004).

We initiated a multi-year research project in 2005 to test the hypothesis that striped bass played a major role in blueback herring declines in the upper Connecticut River. This study, funded through a State Wildlife Grant (SWG T-1) and hereafter referred to as the "SWG Project", involved assessments of striped bass distribution, size structure, and food habits in the upper Connecticut River (region from Wethersfield, CT to Holyoke, MA) during May-June (Davis et al. 2009a). Additional data beyond that collected in the SWG project were needed to accurately quantify the impact of striped bass predation on blueback herring; in particular, contemporary estimates of striped bass absolute abundance (hereafter referred to as "population size", the target population being the aggregation of striped bass present in the study stretch during the spring migration season) were required to update previous estimates (Savoy 1995).

This research project was designed to estimate striped bass population size using a mark-recapture approach (Hayes et al. 2007). All mark-recapture studies involve two basic components: 1) marking of individual organisms with a tag or some other recognizable mark, and 2) efforts to recapture those marked individuals on one or more subsequent occasions (Pine et al. 2003). A variety of statistical models can be applied to mark-recapture data to estimate population size.

Previous studies have estimated striped bass population size in the Connecticut River using a "closed" population model (Savoy 1995). Closed population models assume that: a) the

study population is free of unknown changes in abundance during the study period (no deaths, births, emigration or immigration); b) capture probability is equal among all fish in each sample; and c) tags or marks are not lost or overlooked (Pine et al. 2003; Lukacs 2009). Researchers captured and tagged striped bass in the lower Connecticut River (Old Saybrook to Windsor, CT) during April – June 1994, and relied primarily on recreational anglers to recapture and report tagged fish. Total recreational catch of striped bass in the Connecticut River was estimated from data provided by the Marine Recreational Fishery Statistical Survey and the 1994 CDEP Volunteer Angler Survey (CDEP, unpublished data). The Lincoln-Peterson model (Hayes et al. 2007) was used to estimate striped bass population size for the entire stretch of the Connecticut River within Connecticut during April – June 1994.

The assumption of population closure was likely violated for this study as the Connecticut River striped bass population is "open" (movement from or into the river is unrestricted). Application of closed population models to open populations produces biased estimates of population size (Pine et al. 2003); the magnitude and direction of bias depend on the nature and severity of assumption violations. In addition, studies employing closed population models, even if being conducted in systems that are physically closed, should generally be restricted to short time periods ($\leq$ 1 month) to minimize violation of the closure assumption resulting from deaths and/or recruitment into the target population (Pine et al. 2003). The Lincoln-Peterson model also assumes only two sampling occasions (one sample during which fish are marked, one sample during which fish are recaptured) (Pine et al. 2003) - this assumption is obviously violated for a study in which fish are marked and recaptured on multiple occasions throughout the study season.

Alternate closed model approaches could provide more accurate estimates of striped bass population size in the Connecticut River. Violation of the population closure assumption may be reduced by estimating population size over shorter time intervals (Pine et al. 2003). The Schnabel mark-recapture model, another type of closed population model, allows for more than two sampling occasions and is therefore more appropriate for a study incorporating multiple marking/recapture samples (Pine et al. 2003). Both the Lincoln-Peterson and Schnabel models are computationally-simple and economical as they require only batch marks (e.g. a simple fin clip). However, heterogeneity in capture probability is a chronic source of bias for studies using these models (Pine et al. 2003). Study designs that compile individual capture histories (i.e. all

fish are given a unique mark or tag) allow for the use of more statistically rigorous closed models. For example, the software program MARK (White and Burnham 1999) uses maximum likelihood estimation to fit a suite of closed models to individual capture history data. These models allow for heterogeneity in capture probabilities, and are therefore more robust to violations of the underlying assumptions of closed models (Pine et al. 2003).

The alternate closed model approaches discussed above, while more appropriate than the Lincoln-Petersen model, are still subject to bias because of the open nature of the Connecticut River striped bass population. The most appropriate approach to the problem is the application of an "open" population model such as the Jolly-Seber (Schwarz and Arnason 2009). The Jolly-Seber model requires compilation of individual capture histories, and allows for population changes due to movement, mortality, and recruitment (Pine et al. 2003). A final approach is the application of robust mark-recapture models, a "hybrid" study design that employs both closed and open population models to estimate abundance during a series of short time intervals within the study period (Kendall 2009). This approach is robust to both temporary emigration from the study site and heterogeneous capture probabilities (Pine et al. 2003). Both the open and robust model approaches are more appropriate than closed population models – however, potential drawbacks include the need for relatively high recapture rates and multiple recaptures of some individuals (Pine et al. 2003). In addition, open population models require much higher recapture rates than closed models to provide comparable levels of precision (Hayes et al. 2007).

Given these considerations, we designed our tag-recapture study to incorporate two complementary approaches. The primary approach sought to estimate population size using either a robust or open population model. We planned to intensively sample a small area of the upper CT River to achieve the high recapture rates required for these approaches. If successful, population size for this small area would be estimated on weekly intervals. These weekly estimates of absolute abundance would then be used to calibrate weekly estimates of relative abundance (electrofishing catch-per-hour, or CPH) for this study area. This calibration would be used to estimate absolute abundance from relative abundance estimates available for the four other river sections sampled during SWG Project operations. Ultimately, these five estimates of absolute abundance would be used to extrapolate population size estimates at weekly intervals for the entire river stretch from Wethersfield CT to Holyoke MA. Open and robust mark-recapture models require individual capture histories; therefore the success of this approach was

directly reliant on sufficient electrofishing recapture rates (detailed capture histories would not be available for fish recaptured by anglers).

The secondary approach would estimate population size using a closed population model. The most desirable avenue would be use of individual capture histories (compiled via electrofishing) to fit a suite of maximum likelihood models using MARK (White and Burnham 1999; Lukacs 2009). An alternate closed model approach would be the application of a Schnabel mark-recapture model. Anglers would serve as the primary source of recaptures, and angler catch would be estimated from a creel survey of recreational anglers on the Connecticut River (Davis et al. 2009b). This approach would estimate population size over a broader area of the Connecticut River (i.e. fish tagged and recaptured in areas other than Windsor Locks would be considered in the analysis).

This goal of this research project (hereafter referred to as the "Mark-Recapture Project") was to estimate striped bass population size in the upper Connecticut River (Wethersfield, CT to Holyoke, MA) during May-June. The specific objectives of the Mark Recapture Project were:

Objective 1: conduct an intensive mark-recapture exercise in the Windsor Locks section of the Connecticut River to estimate absolute abundance of striped bass within this area at weekly intervals using either an open or robust mark-recapture model.

Objective 2: calibrate weekly estimates of relative abundance (electrofishing CPH) obtained in the Windsor Locks section to weekly absolute abundance estimates.

Objective 3: use this calibration to estimate absolute abundance from relative abundance in the four other river sections sampled during SWG Project sampling.

Objective 4: use these five estimates of absolute abundance to extrapolate population size estimates at weekly intervals for the entire river stretch from Wethersfield CT to Holyoke MA.

Objective 5: use individual capture histories compiled during the intensive mark-recapture exercise to estimate absolute abundance of striped bass in Windsor Locks during May-June using maximum-likelihood closed population models.

Objective 6: use all tag recaptures (electrofishing and angler) and creel survey data to estimate absolute abundance of striped bass in the river stretch from Wethersfield CT to Holyoke MA during May-June using a Schnabel mark-recapture model.

Methods

Field Operation

Field sampling occurred during May-June of 2007 and 2008. Sampling was initiated as soon as possible in May (based on river conditions and manpower availability) and was terminated in June when low river flows prevented safe navigation. Night-time boat electrofishing (Fig. 1) was used to capture striped bass following protocols established for SWG Project sampling (Davis et al. 2009a).

The simultaneous execution of the Mark-Recapture and SWG projects in 2007 required multiple crews to operate independently in different portions of the river on the same night. The Windsor Locks area (Fig. 2) was selected for intensive sampling for the Mark-Recapture Project because it had yielded the highest striped bass catch rates during previous SWG project sampling (Davis et al. 2009a). Mark-Recapture Project procedure called for 3 nights each week of sampling. Hence the sampling schedule for both projects required sampling at WL 4 nights each week (Tue-Fri), with Tuesday nights serving as a dual purpose SWG Project and Mark-Recapture Project sample night (i.e. data collected on this night would be used for both projects). SWG project sampling at other sites (Fig. 1) included tagging as well.

SWG Project sampling did not occur during 2008; sampling was limited to that supported by the Mark-Recapture Project.

All striped bass captured were enumerated, measured (TL, mm), and fish ≥ 300 mm were tagged with a uniquely-coded internal anchor FLOY tag (Fig. 3). Tags contained a unique 5-digit id number, as well as a phone number that anglers could call to report captures of tagged fish. In 2008, two different colored tags were used to indicate different rewards for report of the tag to anglers (see below). All tagged striped bass recaptured during electrofishing operations were recorded; all striped bass (tagged or untagged) were released alive after capture.

Angler Outreach

The Schnabel closed model approach relies on reports of tagged fish captured by anglers. We offered monetary rewards to maximize angler reporting (Pollock et al. 2001). In 2007, we offered a $15 reward for tag reports. A high-reward tag ($50) was added in 2008 to increase angler interest in the program and allow for estimation of standard tag reporting rates (Pollock et al. 2001). Under-reporting of relatively low-reward tags is a potential source of bias in

population size estimates (Pollock et al. 2001). High-reward tags were a different color than standard reward tags (high-reward = red, standard reward = yellow).

We employed outreach activities to inform anglers of the study and the monetary rewards offered for tag reports. Posters were placed at all public boat launches and other popular fishing locations along the Connecticut River in CT and MA (Fig. 3). Informational posts were made on local internet fishing forums, and local newspaper fishing columnists were contacted. In 2008, letters were sent to all tackle shop owners informing them of the study and requesting that they post an enclosed poster advertising the program (Appendix 1). CDEP creel survey agents also informed all striped bass anglers interviewed of the tagging program.

Mark-Recapture Models

The open population model most appropriate for estimating abundance in fisheries applications is the Jolly-Seber model (Pine et al. 2003). The Jolly-Seber model uses maximum likelihood estimation to estimate capture probability at each sampling occasion and apparent survival rate between sampling occasions (Schwarz and Arnason 2009). Depending on model parameterization, capture probability and survival rate may be fixed across the sampling period or time-dependent (Schwarz and Arnason 2009). The net number of new entrants into the population (net recruitment) at each sampling occasion is also estimated; population size at each sampling occasion is then estimated as some function of net recruitment and survival in the preceding interval (Schwarz and Arnason 2009). Program MARK (White and Burnham 1999), available free on the world-wide web, is capable of fitting Jolly-Seber models to capture history data. MARK uses Aikaike's Information Criterion (AIC) as a criterion for model parsimony, and also provides Goodness-of-Fit (GOF) tests that indicate whether a model is appropriate for the capture history data (Lukacs 2009). The statistical procedures used to fit Jolly-Seber models are highly complex and are not detailed here for the sake of brevity; several authors have provided in-depth overviews (Seber 1982; Lebreton et al. 1992; Schwarz and Arnason 2009).

Program MARK (White and Burnham 1999) can also fit a suite of closed population models to individual capture history data using maximum likelihood estimation (Pine et al. 2003). These models estimate three parameters: capture probability, recapture probability, and population size (Lukacs 2009). Capture and recapture probabilities can be specified as equal or unequal; they may also be time-dependent or fixed across the study period (Lukacs 2009). The suite of closed models available in MARK feature different parameterizations that account for

heterogeneity in capture probabilities (due to factors such as "trap response"), a common source of bias in closed population modeling (Pine et al. 2003). The likelihood estimation used to fit these models are highly complex and are not detailed here for the sake of brevity; in-depth overviews are provided elsewhere (Otis et al. 1978; Huggins 1989; Lukacs 2009).

The robust mark-recapture design represents a hybridization of the two approaches described above (Pine et al. 2003). A robust design consists of a series of short-term samples (secondary sampling periods) clustered within a longer time interval (primary sampling periods) (Pine et al. 2003). Closed population models (such as the suite of maximum likelihood models described above) are used to estimate abundance within secondary sampling periods, and apparent survival between primary periods is estimated using a Jolly-Seber model (Pine et al. 2003). Program MARK (White and Burnham 1999) is also capable of fitting robust mark-recapture models. In our study, a calendar week would constitute a secondary sampling period, and some longer time interval (e.g. 2 weeks, 1 month – to be determined based on recapture rates) would serve as the primary sampling period. Other authors have provided more detail on estimation procedures for the robust model (Pollock 1982; Kendall 2009).

The Schnabel closed population model was the simplest model we used to estimate striped bass population size. The Schnabel closed population model incorporates multiple marking and recapture samples, a sampling design that is highly recommended for closed population modeling (Pine et al. 2003). Fish are marked and recaptured on multiple occasions, and population size is estimated as (Hayes et al. 2007):

$$N = \frac{\sum_{i=2}^{t} n_i * M_i}{\sum_{i=2}^{t} m_i}, \qquad \text{(equation 1)}$$

where: N = estimated population size; n_i = total fish captured on sampling occasion i; M_i = number of tagged fish at large for sample occasion i; m_i = number of tagged fish recaptured on sample occasion i; and t = number of sampling occasions. For our purposes, every day on which a striped bass was recaptured (either by an angler or during electrofishing) was treated as a sampling occasion. The total catch (n_i) of striped bass ≥ 300mm on each sample day was estimated as the sum of electrofishing catch (if electrofishing was conducted) and estimated angler catch. Electrofishing catch was known; catch by recreational anglers was estimated from creel data from "Zone 4" (the river stretch from Hartford to the MA/CT border (Davis et al.

2009b). For sample days on which a creel survey was not conducted, catch was estimated as the mean catch for that day-type stratum (weekend vs. weekday) within the month.

The number of angler recaptures of standard tags in 2008 was adjusted by estimating standard tag reporting rate. Assuming 100% reporting of high-reward tags, the reporting rate for standard tags can be estimated as (Pollock et al. 2001):

$$\lambda = \frac{R_s N_r}{R_r N_s} \quad \text{(equation 2)}$$

where: λ = standard tag reporting rate (expressed as a proportion); R_s = number of standard tags recaptured; N_r = number of high-reward tags released; R_r =number of high-reward tags recaptured; and N_s = number of standard tags released.

Creel Survey

Estimates of recreational catch of striped bass were needed for the Schnabel closed model approach. Such estimates were available because CDEP personnel conducted a "bus stop" creel survey on the Connecticut River in 2008 (Davis et al. 2009b). This creel survey covered the portion of the Connecticut River between Middletown, CT and the Massachusetts/Connecticut border, and provided estimates of recreational angler effort and catch during the open-water fishing season (Davis et al. 2009b). A detailed description of the creel methodology has been attached (Appendix 2).

Results

Field Operations

Field sampling in 2007 began on 10 April and ended on 15 June. We conducted sampling on 42 nights (Table 1; 22 SWG Project, 14 Mark Recapture Project, 6 dual purpose). Sampling prior to 6 May was limited due to river flooding and manpower availability. During the first two weeks of May sampling, the Windsor Locks sample zone was visited 4 nights a week. The subsequent loss of one of our electrofishing boats to mechanical failure necessitated a reduction to three sample nights a week at Windsor Locks for the remainder of the sampling season. Sampling was discontinued after 15 June because of additional equipment failure, consistent low catch rates, and poor navigability stemming from low water levels.

In 2008, sampling began on 6 May and ended on 11 June; 14 sampling trips were completed (Table 2). All sampling occurred at the Windsor Locks site. Sampling was

discontinued after 11 June because of mechanical failure, low river flows, and persistent low catch rates.

Striped Bass Tagging and Recapture

A total of 662 striped bass was tagged during 2007 sampling operations (Table 3). The majority of fish (n=448) were tagged during Mark-Recapture and dual purpose sample nights in Windsor Locks. A small number of striped bass were euthanized because they failed to recover from handling (Table 3).

Of 41 recaptures in 2007, anglers accounted for more than 80% (Table 4). Almost half of the recaptures (designated "A" in Table 4) of fish tagged in 2007 occurred during the sampling season (4/10/07 – 6/15/07) and within the study stretch, and were therefore useful for mark-recapture modeling. The A-level recapture rate (2.7%) was comparable to those obtained in previous mark-recapture studies (Savoy 1995).

A total of 535 striped bass was tagged during 2008 sampling operations (Table 3), divided about equally between standard and high-reward tags (289 standard, 246 high-reward). As in 2007, a small number of striped bass were euthanized (Table 3). Of the 26 striped bass recaptures in 2008 (Table 5), anglers provided almost 90%. More than two-thirds of the 2008 recaptures (designated "A" in Table 5) occurred during the sampling season and within the study stretch. The A-level recapture rate was 3.3%. All angler recaptures reported from the CT River ("A" and "B" in Table 5; 10 high-reward returns and 8 standard returns) were used to estimate standard tag reporting rate. Angler recaptures of standard tags from 2006-07 were not included in this analysis as the number of 2006-07 tags at-large in the CT River in 2008 was unknown. Standard tag reporting rate was estimated as 68% (from equation 2: $R_s = 8$, $N_r = 246$, $R_r = 10$, $N_s = 289$, $\lambda = [8 * 246] / [10 * 289] = 0.68$).

Population Size Estimates

Low recapture rates (< 1% in both years) during electrofishing operations and lack of multiple recaptures of the same fish precluded application of either a Jolly-Seber or robust mark-recapture model in either year. Therefore, Objectives 1 -4 could not be met.

We attempted to fit closed population models to individual capture histories of striped bass tagged and recaptured during electrofishing operations in Windsor Locks. Program MARK was used to fit three candidate models: 1) capture probability (p) and recapture probability (c) equal and time-dependent ($p_t = c_t$); 2) capture probability and recapture probability unequal but

constant across time ($p.$, c.); and 3) capture probability and recapture probability equal and constant across time ($p. = c.$) (Lukacs 2009). The most general (i.e. most parameterized) model $p_t = c_t$ received the most support among the candidate models in both years (AIC$_c$ weight = 1.00 for both years) but failed GOF tests by a large margin. The variance inflation factor ($\hat{c}$) for the $p_t = c_t$ model in both years (2007: $\hat{c}$ = 9.3; 2008: $\hat{c}$ = 14.3) exceeded the value of $\hat{c}$ = 3.0, a threshold beyond which a model should be considered a poor fit to the data (Lebreton et al. 1992; Cooch and White 2009). Accordingly, the models tested were not considered valid, and Objective 5 could not be met.

The Schnabel closed population model was used to estimate striped bass population size in 2008 (analysis was not possible for 2007 due to a lack of creel data). The study period was restricted to the month of May because: a) the recommended study period length for closed population models is < 1 month (Pine et al. 2003), b) all applicable recaptures occurred during the month of May (designated "A" in Table 5), and c) only 7% (n = 35) of the striped bass tagged in 2008 were tagged after the month of May. In addition, the applicable study area was restricted to the stretch of the Connecticut River between Hartford and the CT/MA border because the majority of "A" recaptures occurred in this area (the lone exception being an angler recapture reported from Springfield, MA on 5/17/08 – this recapture was excluded from Schnabel model calculations). The number of angler recaptures of standard tags was adjusted using the estimated standard tag reporting rate (Table 6). The Schnabel model yielded an estimate of 56,207 (95% CI = 36,737 – 89,931) striped bass ≥ 300 mm TL in the Connecticut River between Hartford and the MA/CT border during May 2008 (Table 6). Because fewer than 25 total recaptures were recorded, recaptures were treated as a Poisson variable for the purposes of confidence interval estimation (Hayes et al. 2007).

Discussion

Low recapture rates during electrofishing operations precluded application of Jolly-Seber and robust mark-recapture models in either year of our study. Several factors may have contributed to low recapture rates. The total number of striped bass tagged in both years fell short of target numbers. During project planning, we estimated a total of 1,400 striped bass tagged per season in Windsor Locks alone (based on SWG Project electrofishing operations in 2005-06). However, our sampling season was terminated earlier than expected in both years (before the end of June) due to a combination of mechanical failure and lower-than-expected

river flows. Mechanical failure also necessitated a reduction in sampling effort during the season in both years. Low river flows in the latter part of both sample seasons created unfavorable conditions for striped bass migration into the upper Connecticut River, leading to lower electrofishing catch rates than expected for much of late-May and early-June. Rates of striped bass movement through the Windsor Locks study zone may also have been greater than expected. Whatever factors contributed to produce low encounter probabilities, it is clear that any study seeking to estimate striped bass population size in the Connecticut River using either and open or robust model approach will require a much larger sampling effort than that executed during this study.

Our efforts to apply closed population models to estimate striped bass population size in the upper Connecticut River during May-June were partially successful. Relatively high rates of angler recapture allowed application of a Schnabel mark-recapture model. The estimate provided by the Schnabel model should be viewed with caution, as violation of the population closure assumption was evident (failure of maximum likelihood closed population models to fit the data, recovery of tags outside the study area). Although biased to an unknown degree, the Schnabel estimate is nevertheless useful for our efforts to test the hypothesis that striped bass have played a major role in blueback herring declines within the Connecticut River. Preliminary modeling suggests that a striped bass population of approximately 65,000 individuals may be able to consume over 220,000 herring during the spring migration season, a number comparable to passage at Holyoke Dam prior to the population crash (Davis et al. 2009a). Beyond use in our research program, the estimates of striped bass population size derived here may be useful to managers that regulate the increasingly popular recreational fishery for striped bass in the Connecticut River (Jacobs et al. 2004).

Future work may seek to determine the severity of the bias associated with closed model estimates of striped bass population size via movement studies. Telemetry studies that track the movements of individual striped bass may give insight into the relative rate of movement in/out of the study area and consequently the degree to which the closure assumption is violated (Pine et al. 2003). Telemetry can also be used to provide empirical estimates of capture probability (Pine et al. 2003). Given the large sampling effort that may be required to successfully apply an open or robust mark-recapture model, telemetry studies may be a more viable approach to improving estimates of striped bass population size in the Connecticut River.

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Table 1. Summary of electrofishing sampling effort by sample night in 2007. Site codes are as follows: WF = Wethersfield, FR = lower Farmington River, WL = Windsor Locks, EF = Enfield, HK = Holyoke, MA. Samples conducted as part of the SWG Project and Mark-Recapture Project are denoted as "SWG" and "MR", respectively ("Dual" = dual purpose nights serving both projects).

Period Start Date	Date	Site	Project	Transects Completed	Total Shocking Time (s)
4/08[a]	4/10	WF	SWG	3	1900
	4/13	FR	SWG	3	1980
5/06[b]	5/06	WF	SWG	5	3295
	5/07	FR	SWG	5	3271
	5/08	WL	Dual	4	2424
	5/09	EF	SWG	5	2984
	5/09	WL	MR	4	2029
	5/10	HK	SWG	3	1915
	5/10	WL	MR	4	2211
	5/11	WL	MR	5	2407
5/13	5/13	WF	SWG	5	3357
	5/14	FR	SWG	4	2836
	5/15	WL	Dual	4	2288
	5/16	EF	SWG	3	1461
	5/16	WL	MR	3	1425
	5/17	HK	SWG	3	2023
	5/17	WL	MR	4	1960
	5/18	WL	MR	5	2616
5/20[c]	5/21	FR	SWG	5	3316
	5/22	WL	Dual	4	2474
	5/23	WF	SWG	4	2636
	5/23	WL	MR	3	1848
	5/24	HK	SWG	3	1786
	5/25	WL	MR	6	3551
5/27[d]	5/27	WF	SWG	6	3955
	5/28	FR	SWG	4	2666
	5/29	HK	SWG	3	1380
	5/30	WL	Dual	4	2337
	5/31 (AM)	WL	SWG	5	2479
	5/31 (PM)	WL	MR	4	3197
	6/01	WL	MR	5	3292
6/03	6/03	WF	SWG	5	3220
	6/04	FR	SWG	3	1970
	6/05	HK	SWG	3	2047
	6/06	WL	Dual	4	2389
	6/07	WL	MR	4	2834
	6/08	WL	MR	5	3036

Table 1 (cont'd)

Period Start Date	Date	Site	Project	Transects Completed	Total Shocking Time (s)
6/10[e]	6/10	WF	SWG	4	2632
	6/12	HK	SWG	3	1723
	6/13	WL	Dual	3	1532
	6/14	WL	MR	4	2708
	6/15	WL	MR	3	1413

[a] WL, EF, HK not sampled due to limited availability of personnel
[b] No sampling 4/14/07 – 5/5/07 due to flooding and limited availability of personnel
[c] No sampling 5/20 due to flooding; WF sampled 5/23 due to EF launch closure
[d] Sampling schedule changed due to logistical constraints (see "Summary of Field Sampling Operations"); 5/31 (AM) sample at WL was experimental daytime electrofishing to assess diel patterns in striped bass gut fullness
[e] No sampling 6/11 due to inclement weather; sampling discontinued after 6/15 due to equipment malfunction, low catch, and large portions of the sample stretch becoming un-navigable due to low river flows

Table 2. Summary of electrofishing sampling effort by sample night in 2008. All sampling took place at Windsor Locks.

Period Start Date	Date	Transects Completed	Total Shocking Time (s)
5/4	5/6	3	2637
	5/8	6	3954
5/11	5/11	4	3295
	5/13	5	4712
	5/15	5	4415
5/18	5/18	4	3868
	5/20	5	3851
	5/22	4	3428
5/25	5/27	4	2758
	5/28	3	2901
	5/29	4	2750
6/1	6/1	4	2725
	6/5	3	2078
6/8	6/11	2	760

Table 3. Summary of striped bass collections in 2007-08. Fish < 300 mm TL were released without tags. The recapture columns refer to recaptures of striped bass tagged during that year's sampling operations. These fish were released without additional tags.

Year	Captured	Euthanized	Released – Untagged	Released – Tagged	Electrofishing Recaptures	Angler Recaptures
2007	1049	9	371	662	6[a]	31
2008	591	3	50	535[b]	3	20

[a]One striped bass tagged during 2006 SWG Project pilot tagging study was recaptured via electrofishing in 2007

[b] 246 high-reward tags, 289 standard tags

Table 4. Striped bass recaptures in 2007. Recapture classifications are as follows: “2006” = recaptures of fish tagged during SWG Project pilot tagging study in 2006; “A” = recaptures made during the sampling season and within the study stretch (WE to HK); “B” = recaptures made during the sampling season, within the Connecticut River but outside of the study stretch; “C” = recaptures made after the sampling season, within the Connecticut River and within the study stretch; “D” = recaptures made after the sampling season, within the Connecticut River but outside the study stretch; “E” = recaptures made during the sampling season within Long Island Sound; “F” = recaptures made after the sampling season within Long Island Sound (LIS); “OS” = recaptures of fish tagged in 2007 made outside the State of Connecticut; “UK” = unknown. Site codes are listed in Table 1.

Tag Number	Tag Site	Capture Date	Recapture Location	Recapture Date	Recapture Type	Recapture Class
168	WF	2006	NJ (Raritan Bay)	4/04	Angler	2006
78	WL	2006	CT River (WL)	5/12	Angler	2006
242	FR	2006	CT River (Windsor)	5/27	Angler	2006
321	FR	4/13	CT River (FR)	5/26	Angler	A
647	WL	5/18	CT River (WL)	6/07	Angler	A
471	FR	5/14	CT River (Hartford)	5/15	Angler	A
582	WL	5/16	CT River (WL)	5/22	Angler	A
382	WL	5/08	CT River (WL)	5/15	Angler	A
714	WL	5/23	CT River (WL)	5/25	Angler	A
399	WL	5/08	CT River (WF)	5/30	Angler	A
2556	WL	5/22	CT River (Hartford)	5/30	Angler	A
353	WL	5/08	CT River (FR)	5/23	Angler	A
650	WL	5/18	CT River (WL)	5/19	Angler	A
617	WL	5/17	CT River (WL)	6/01	Angler	A
507	WL	5/09	CT River (Hartford)	5/26	Angler	A
2530	EF	5/16	CT River (mouth)	6/13	Angler	B
457	HK	5/10	CT River (mouth)	5/16	Angler	B
306	FR	4/13	CT River (Chicopee)	8/30	Angler	C
479	FR	5/14	CT River (mouth)	6/19	Angler	D
2642	WF	5/27	CT River (Essex)	6/18	Angler	D
449	FR	5/14	CT River (mouth)	7/03	Angler	D

Table 4 (cont'd)

Tag Number	Tag Site	Capture Date	Recapture Location	Recapture Date	Recapture Type	Recapture Class
2688	WL	6/01	CT River (mouth)	6/26	Angler	D
2527	EF	5/16	LIS (Old Saybrook)	6/08	Angler	E
580	WL	5/11	LIS (Race)	6/15	Angler	E
628	WL	5/18	LIS (Orient Point)	7/04	Angler	F
283	FR	4/13	LIS (Old Lyme)	7/11	Angler	F
2628	HK	5/24	LIS (Westbrook)	7/18	Angler	F
2807	WL	6/07	LIS (Race)	8/04	Angler	F
259	FR	4/13	MA (Merrimack River)	7/08	Angler	OS
724	WL	5/23	MA (Cape Cod Canal)	6/03	Angler	OS
577	WL	5/11	NJ (Seaside Park)	11/25	Angler	OS
272	FR	4/13	ME (Saco River)	9/08	Angler	OS
Unknown[a]	Unknown	Unknown	CT River (Keeney Cove)	10/13	Angler	UK
Unknown[a]	Unknown	Unknown	CT River (Crow Point Cove)	10/20	Angler	UK
21	WL	2006	CT River (WL)	5/09	Electrofish	2006
373	WL	5/08	CT River (WL)	5/17	Electrofish	A
526	WL	5/09	CT River (WL)	5/18	Electrofish	A
564	WL	5/11	CT River (WL)	5/25	Electrofish	A
721	WL	5/23	CT River (WL)	6/06	Electrofish	A
2569	WL	5/22	CT River (WL)	5/25	Electrofish	A
2620	HK	5/24	CT River (WL)	5/31	Electrofish	A

[a] Angler caught 3 tagged fish on 10/13/07 and 1 tagged fish on 10/20/07 but did not record tag numbers

Table 5. Striped bass recaptures in 2008. Recapture classifications are as follows: “2006” = recaptures of fish tagged during SWG Project pilot tagging study in 2006; “2007” = recaptures of fish tagged in 2007; “A” = recaptures made during the sampling season and within the study stretch (WE to HK); “B” = recaptures made during the sampling season, within the Connecticut River but outside of the study stretch; “OS” = recaptures of fish tagged in 2007 made outside the State of Connecticut. Site codes are listed in Table 1.

Tag Number	Reward	Tag Site	Capture Date	Recapture Location	Recapture Date	Recapture Type	Recapture Class
66	Standard	FR	2006	CT River (FR)	5/18	Angler	2006
707	Standard	WL	2007	CT River (WL)	4/30	Angler	2007
2945	Standard	HK	2007	CT River (Springfield, MA)	5/20	Angler	2007
5253	High	WL	5/06	CT River (WL)	5/12	Angler	A
5264	High	WL	5/06	CT River (Springfield, MA)	5/17	Angler	A
5296	High	WL	5/06	CT River (WL)	5/09	Angler	A
5233	High	WL	5/06	CT River (WL)	5/22	Angler	A
5236	High	WL	5/06	CT River (WL)	5/24	Angler	A
5245	High	WL	5/06	CT River (WL)	5/08	Angler	A
5276	High	WL	5/06	CT River (WL)	5/14	Angler	A
5246	High	WL	5/06	CT River (WL)	5/11	Angler	A
2499	Standard	WL	5/06	CT River (Hartford)	5/10	Angler	A
2452	Standard	WL	5/06	CT River (WL)	5/08	Angler	A
1219	Standard	WL	5/06	CT River (WL)	5/10	Angler	A
2489	Standard	WL	5/06	CT River (Hartford)	5/24	Angler	A
1757	Standard	WL	5/22	CT River (WL)	5/23	Angler	A
1204	Standard	WL	5/06	CT River (South Windsor)	5/22	Angler	A
5016	High	WL	5/06	CT River (Rocky Hill)	6/09	Angler	B
5215	High	WL	5/08	CT River (Rocky Hill)	5/14	Angler	B
2044	Standard	WL	5/18	CT River (Rocky Hill)	6/01	Angler	B
1034	Standard	WL	5/08	CT River (Old Lyme)	5/18	Angler	B
5279	High	WL	5/06	RI (Newport)	5/28	Angler	OS
2848	Standard	WL	5/06	RI (Barrington)	6/01	Angler	OS
1764	Standard	WL	5/22	CT River (WL)	5/27	Electrofish	A

Table 5 (cont'd)

Tag Number	Reward	Tag Site	Capture Date	Recapture Location	Recapture Date	Recapture Type	Recapture Class
2711	Standard	WL	5/27	CT River (WL)	5/30	Electrofish	A
2841	Standard	WL	5/06	CT River (WL)	5/22	Electrofish	A

Table 6. Schnabel mark-recapture estimate of population size for striped bass ≥ 300 mm TL in the river stretch between Hartford and the MA/CT border in May 2008. All sample days on which striped bass were recaptured via electrofishing and/or anglers are shown. Angler catch for each day was estimated from creel survey data.

Date	Angler Catch	Electrofishing Catch	Total Catch (n_i)	Angler Recaps	Electrofishing Recaps	Total Recaps (m_i)	Tags-at-Large (M_i)	$n_i * M_i$
5/7	101	0	101	0	0	0	173	17473
5/8	101	77	178	2	0	2	173	30794
5/9	82	0	82	1	0	1	249	20418
5/10	309	0	309	2	0	2	249	76941
5/11	139	21	160	1	0	1	249	39840
5/12	8	0	8	1	0	1	270	2160
5/13	101	11	112	0	0	0	270	30240
5/14	249	0	249	1	0	1	281	69969
5/15	101	35	136	0	0	0	281	38216
5/16	101	0	101	0	0	0	316	31916
5/17	139	0	139	0	0	0	316	43924
5/18	139	33	172	0	0	0	316	54352
5/19	101	0	101	0	0	0	349	35249
5/20	101	62	163	0	0	0	349	56887
5/21	101	0	101	0	0	0	411	41511
5/22	154	44	198	2	1	3	411	81378
5/23	101	0	101	1	0	1	453	45753
5/24	139	0	139	2	0	2	453	62967
5/25	139	0	139	0	0	0	453	62967
5/26	117	0	117	0	0	0	453	53001
5/27	101	22	123	0	1	1	453	55719
5/28	42	16	58	0	0	0	474	27492
5/29	42	0	42	0	0	0	490	20580
5/30	101	11	112	0	1	1	490	54880
5/31	139	0	139	0	0	0	500	69500

Table 6 (cont'd).

Date	Angler Catch	Electrofishing Catch	Total Catch (n_i)	Angler Recaps	Electrofishing Recaps	Total Recaps (m_i)	Tags-at-Large (M_i)	$n_i * M_i$
Total	2948	332	3280	13	3	16		1124127
Adjusted Total[a]				16[a]		19[a]		

Equation 1: (1124127) / (19 + 1) = 56,207

[a] Anglers reported 6 standard tags; adjusted total using estimated standard tag reporting rate = (6/0.68) = 9, i.e. 3 additional returns

Figure 1. Night electrofishing with the Smith-Root boat.

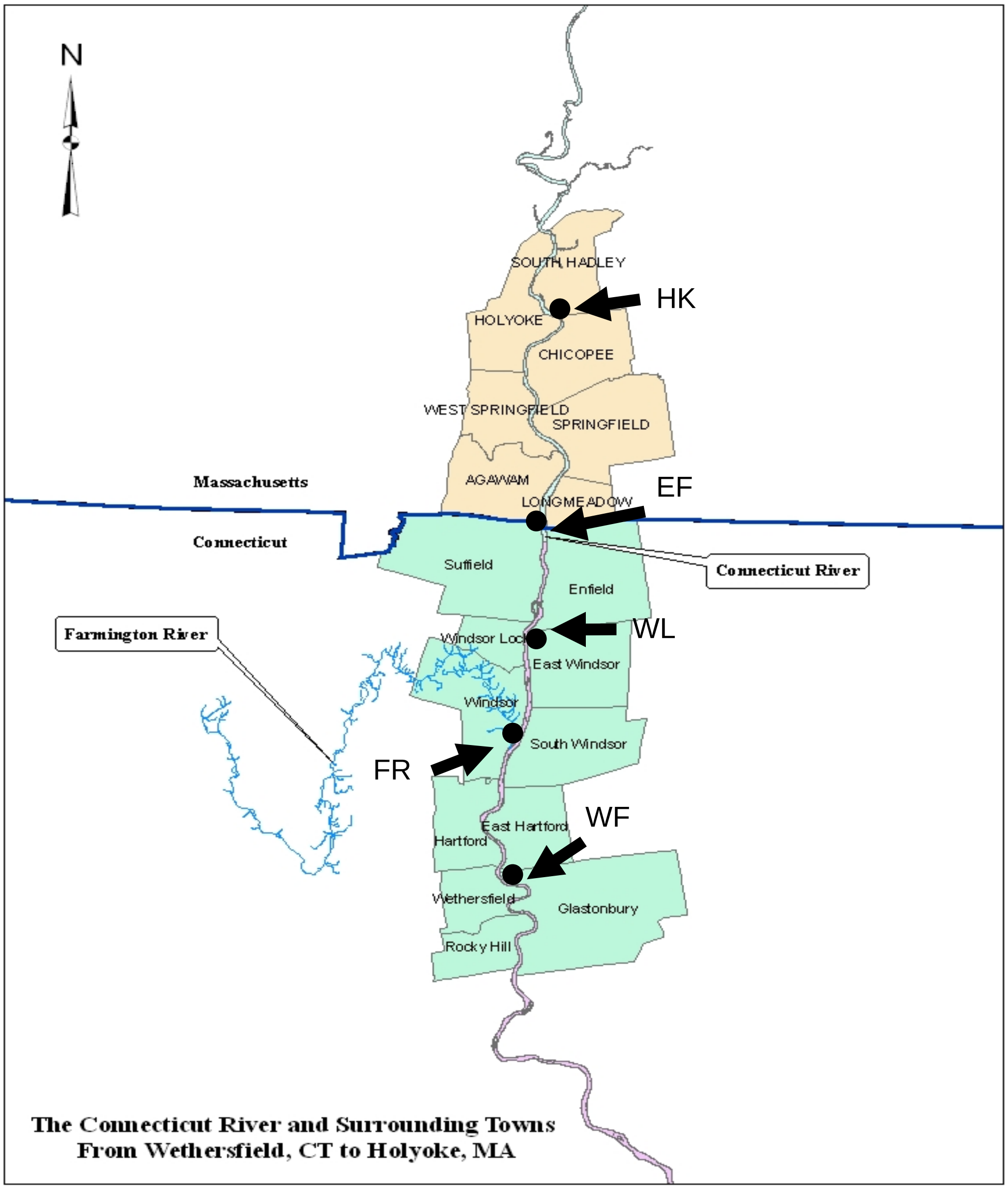

Figure 2. Site map of Connecticut River study area, with the five sample zones indicated: Wethersfield (WF), lower Farmington River (FR), Windsor Locks (WL), Enfield (EF), and Holyoke (HK).

Figure 3. Poster used to inform anglers of the tag rewards in 2008. Note close-up view of a uniquely-coded FLOY internal anchor tag; the unique 5-digit ID code can be seen to the left, while the phone number for anglers to call to report recaptures can be seen to the right.

Appendix 1. Cover letter sent to tackle shop owners. Addressee and date fields were completed using Mail Merge Utility.

University of Connecticut
Department of Ecology and Evolutionary Biology

College of Liberal Arts
and Sciences

April xx, 2008

Tackle shop name
Tackle shop address
Tackle shop address

Dear Tackle Shop Owner,

The University of Connecticut, in cooperation with the Connecticut Department of Environmental Protection and the Connecticut Long Island Sound Fund, is conducting a tagging study of striped bass in the Connecticut River. This study is part of a larger effort to determine the effect of striped bass predation on river herring and American shad. Our uniquely-coded tags also have our phone number (**860-486-4694**) that anglers should call if they catch a tagged striped bass.

There is a monetary reward of $15 or $50 for tag reports. Anglers <u>must</u> be able to report the 5 digit code on the tag to receive the reward.

Please post the enclosed flyer in your tackle shop and help us inform anglers about our research and the reward. The success of our research, and our efforts to manage the fisheries resources of the Connecticut River, depend on participation from the fishing public. Thanks in advance for your assistance and best wishes for a successful 2008 fishing season.

Sincerely,

Justin Davis
Graduate Research Assistant
University of Connecticut
75 North Eagleville Road
Storrs, CT 06269-3043
(860) 486-4694
justin.davis@ct.gov

Appendix 2: Connecticut River Creel Methodology

Introduction

The Connecticut River is the largest water body in Connecticut. It traverses the center of the state for 70 miles; from the Massachusetts border to the town of Old Saybrook on Long Island Sound. The river is second only to the Susquehanna in average daily discharge volume (333 m^3/sec) of rivers along the US Eastern Seaboard north of Georgia (Merriman and Thorpe 2004). Tides influence river elevations in the area south of the city of Hartford.

An angler survey using an access point Bus Stop design (Jones and Robson 1991; Pollock et al. 1994) was conducted on the Connecticut River south of Hartford during 1997-98 (Howell and Molnar 1999; Jacobs et al. 2004). Spring surveys of shad and striped bass fisheries have been conducted north of Hartford on a periodic basis (Savoy and Benway 2006). These surveys identified a number of major seasonal fisheries. Among these are spring fisheries for American shad, striped bass and white perch. The shad fishery is centered north of Hartford while the striped bass fishery takes place along the entire river. The majority of the white perch fishery is located in the southern portion of the river. In addition, there is anecdotal information to suggest that an early spring northern pike fishery exists along much of the Connecticut River. In late spring and early summer, most effort shifts to black bass (largemouth and smallmouth bass) and catfish. Based on tournament permits filed with the DEP, there were 106 competitive fishing tournaments in 2006. These tournaments took place throughout the spring, summer and into the fall, with peak activity in July -August. During the summer, shore-based panfish and catfish angling becomes increasingly important. Panfish, hickory shad, and black bass fishing dominate angler activity in the fall.

While the 1997-98 survey provided extensive spatial and temporal coverage, it was not comprehensive. Coverage was incomplete in the spring and fall, and the river north of Hartford was not surveyed. Moreover, the data from that survey is now ten years old. The current survey will build on previous work and create a more comprehensive and contemporary picture of the river's fishery. It will also provide a baseline for long-term assessments of Connecticut River fishing activity.

Methods

Creel Design

A bus stop survey (Pollock et al. 1994) with a stratified random design was planned. This design would: 1) obtain data that were comparable with the 1997-98 survey done by Howell and Molnar (1999), and 2) maximize sampling efficiency for a resource with multiple, well defined, widely-dispersed access locations. The 1997-98 survey divided the river from Hartford to Long Island Sound into three manageable Survey Zones (Table 1, Fig. 1). To completely survey the Connecticut portion of the Connecticut River, a fourth Survey Zone was added to those of the historical survey. This Survey Zone covers the area north of Hartford to the Massachusetts state line.

Within each Survey Zone, interview sites ("bus stops") are selected. These survey sites consist of the most popular shore fishing sites and all public boat launches within the Zone. Each route has 9-12 bus stops, which are visited in a fixed pattern. On each sample day, a start location and route direction (clockwise or counter-clockwise) are randomly assigned. Each bus stop is then visited sequentially according to the fixed route. There is an allotted "wait time" for each stop that is determined using prior

knowledge of the relative angler usage of the site and the total time allowed for the route. More heavily used sites have longer wait times. During these wait times, creel agents make boat trailer (if at a launch) and shore angler counts and subsequently interview all returning boat anglers and as many shore anglers as time permits

Table 1. Survey Zones for the Connecticut River angler survey.

Zone number	Location	Length of Zone (km)	Covered in 1997-98 survey?
1	I-95 bridge to Haddam Bridge	20 km	Yes
2	Haddam Bridge to Arrigoni Bridge (Portland)	23 km	Yes
3	Arrigoni Bridge to Rail Bridge north of Hartford	29 km	Yes
4	Rail Bridge north of Hartford to MA state line	26 km	No

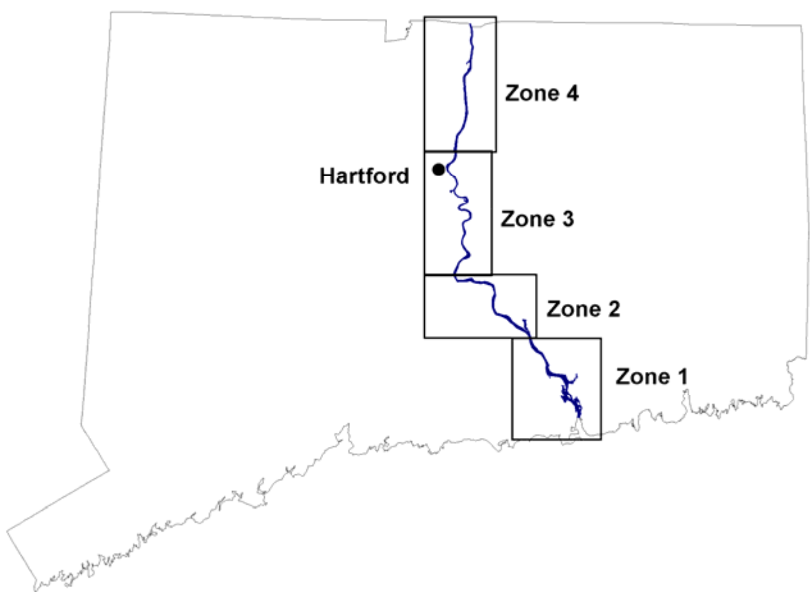

Figure 1. Survey Zones used for Connecticut River angler survey.

Creel Stratification

The survey within each Survey Zone was divided into two-month sample periods that matched the "seasons" used in the 1997-98 survey (Season 1 = March-April, Season 2 = May-June, Season 3 = July-August, Season 4 = September-October). Each Season will be treated as an independent sample unit (i.e. estimates of angler effort and catch will be generated independently for each Season) as major differences in angling activity are expected between Seasons. Each season was stratified by day-type (weekday/weekend), and then sub-stratified by time of day (am/pm). Therefore, each Season was divided

into four strata (weekday am/weekday pm/weekend am/weekend pm) for analyses of angler effort and catch. Stratification most effectively reduces the variance associated with an estimator of a population mean or total when strata are more homogenous internally than the population as a whole (within-stratum variance small relative to between-stratum variance) (Pollock et al. 1994). A significantly higher level of angler usage is expected on weekends relative to weekdays, and angler usage is also expected to differ by time of day. Therefore, the stratification scheme used in this study should minimize within-stratum variance and therefore reduce the variance associated with annual estimates of catch and effort.

Estimation of Angler Effort

Angler effort for a sample day is estimated using the Time Interval Count Method (Robson and Jones 1989; Pollock et al. 1994). Angling effort is recorded and calculated separately for shore and boat anglers. The Time Interval Count Method requires the creel agent upon arrival at each site to count the number of shore anglers and boat anglers (trailer counts are used as a proxy for boat anglers). The creel agent must then note times of angler departures and arrivals during the wait period at the site. Creel agents must be able to distinguish between boat and personal watercraft trailers and count only boat trailers.

An estimate of shore angler effort is calculated for each sample day using the recorded fishing effort of individual shore anglers. Shore angler effort (minutes) is summed for each stop and then divided by the site's wait time. This quantity is then summed for all stops and multiplied by the total time of the creel sample. This result is divided by 60 minutes to obtain an estimate of angler-hours:

Shore angler effort (E_s) for Sample Day: (1)

$$E_s = \left[\frac{T \sum_{i=1}^{n} \frac{1}{w_i} \sum_{j=1}^{m} \frac{e_{ji}}{\pi_j}}{60} \right] / S_h$$

where:
E_s = estimated shore angler effort for the sample day (hours)
T = total route time
W_i = wait time at the ith site in minutes (i = 1,2….n)
e_{ji} = total time in minutes that the jth angler is at the ith site while the clerk is at the site (j = 1, 2, …m)
π_j = AM/PM stratum sampling probability (see below)
S_h = shore angler expansion value for stratum h (see Expansion Values)

The sampling probability term (π_j) adjusts for the AM/PM stratum sampling probability. Because the sample day is divided into two strata (AM and PM), sampled with equal probability, this term is set to 0.5 for all analyses.

A slight modification of this analysis structure is used to estimate boat angling effort for a sample day. Because boat angler effort is based on trailer counts as a proxy of boat anglers, all trailer counts are expanded by an average party size. Howell and Molnar (1999) used a value of 2.0 anglers per boat as an average party size based on interviews from the Connecticut River. This value agrees with the average party size found by (Barry 1988) for anglers on the Housatonic River. The boat angler count is then adjusted by the percentage of boats at the launch that were used by anglers (see Expansion Values).

Boat angler effort (E_b) for Sample Day (angler-hrs): (2)

$$E_b = \left[\left[\frac{T\sum_{i=1}^{n}\frac{1}{w_i}\sum_{j=1}^{m}\frac{e_{ji}}{\pi_j}}{60}\right] * P\right] * B_h$$

where:
E_b = estimated boat angler effort for the sample day (hours)
T = total route time (see below)
W_i = wait time at the ith site in minutes (i = 1,2….n)
e_{ji} = total time in minutes that the jth trailer is at the ith site while the clerk is at the site (j = 1, 2, …m)
π_j = AM/PM stratum sampling probability (Equation 4)
P = average boating party size (= 2)
B_h = boat trailer expansion value for stratum h (see Expansion Values)

Because not all sites on the bus stop route are boat launches, the route time (T) must be adjusted by subtracting time spent at sites that are shore fishing-only locations.

Expansion Values

Boat angler effort estimates produced by the Time Interval Count Method must be corrected to account for the proportion of trailers that are not attributable to angling activity (i.e. belong to recreational boaters). Shore angler effort estimates must also be corrected to account for shore angling that occurs at locations within the Survey Zone that are not surveyed by the bus stop creel. To make these corrections, two stratum-specific expansion values are needed for each Survey Zone: S = the proportion of shore anglers that fish at bus stop locations within the Survey Zone; and B = the proportion of trailers at a bus stop launch that are used for angling (vs. recreational boating). The proportion S will be referred to in this report as the "shore angler expansion value", while the proportion B will be referred to as the "boat trailer expansion value".

To generate shore angler expansion values, survey agents conduct boat-based surveys of a Survey Zone (hereafter referred to as "shore angler counts"). Agents travel the length of a Survey Zone and count all shore anglers, noting how many of these anglers are fishing at bus stop locations. Shore angler counts are conducted multiple times within each creel survey stratum. A shore angler expansion value is then calculated for each stratum:

Shore Angler Expansion Value (3)

$$S_h = \frac{A_h}{N_h}$$

where:
S_h = shore angler expansion value for stratum h
A_h = anglers observed fishing at creel sites during all shore angler counts conducted in stratum h
N_h = total anglers observed during all shore angler counts conducted in stratum h

For the purpose of shore angler expansion values, each Season will only be stratified by weekday/weekend (i.e. same shore angler expansion value will be used to correct am and pm shore angler effort estimates within each day-type). Two shore angler counts will be performed in each stratum (ideally one weekday/one weekend count per month) in each Survey Zone.

Boat trailer expansion values are generated using the same analytical framework. Each launch on a bus stop route is surveyed four times within a Season (one weekday/one weekend survey per month). During the boat launch survey, the creel clerk interviews all boaters using the launch and ascertains whether the boaters are recreational fishermen fishing within the Connecticut River, or recreational boaters/recreational fishermen planning to fish outside the Connecticut River. These data can then be treated in the same manner as described above (Equation 3) to produce a stratum-specific boat trailer expansion value (B_h: the number of boat angler parties interviewed within stratum h as a proportion of all boating parties interviewed within stratum h).

Estimation of Angler Catch and Harvest

Estimates of angler catch and harvest for each sample day are derived using a two-step calculation. In the first step, catch-per-hour and harvest-per-hour of each species recorded in the catch is calculated for each angling mode (boat and shore) using interview data. In the second step, catch-per-hour and harvest-per-hour for each angling mode is multiplied by the estimated effort for that mode (Equations 1-2) to produce an estimate of total catch for that day. Estimates of boat and shore angler catch-per-hour are derived from interview data, and are calculated using different estimators. Boat angler interviews represent completed fishing trips, and boat angler catch-per-hour is therefore estimated using the ratio-of-means estimator (Pollock et al. 1994):

Ratio-of-Means Catch-per-Hour Estimator (4)

$$C_b = \frac{\overline{c}}{\overline{L}}$$

where:
C_b = boat angler catch-per-hour
$\overline{c}$ = mean boat angler catch (across all boat angler interviews for sample day)
$\overline{L}$ = mean trip length (across all boat angler interviews for sample day)

Boat angler interviews may be obtained during ancillary surveys (e.g. boat launch surveys) that occur on days other than those on which bus stop creel surveys are conducted. Therefore, boat angler interviews may be pooled across some suitable time frame (e.g. weekly) and weekly estimates of boat angler catch-per-hour may then be generated and applied to all bus stop creel surveys conducted within that time frame.

Shore angler interviews represent incomplete fishing trips, and therefore the mean-of-ratios estimator is used to calculate shore angler catch-per-hour (Pollock et al. 1994):

Mean-of-Ratios Catch-per-Hour Estimator (5)

$$C_s = \frac{\sum_{i=1}^{n} \frac{c_i}{L_i}}{n}$$

where:
C_s = shore angler catch-per-hour
c_i = catch of shore angler i
L_i = trip length of shore angler i (hours)
n = number of shore angler interviews

Shore angler interviews for trips < 0.5 hours in length are excluded from this calculation to avoid undue influence of chance extreme catch rates on the variance of the mean-of-ratios estimator (Pollock et al. 1994). The mean-of-ratios estimator will also be used for incomplete boat angler interviews obtained during on-water surveys.

Once catch-per-hour for a given species is calculated for each mode (shore, boat) on a sample day, total catch of that species for each mode on that sample day is calculated as (Pollock et al. 1994):

Estimate of Total Catch for a Sample Day (6)

$$\hat{C} = \hat{E}\hat{R}$$

where:
$\hat{C}$ = estimate of total catch by shore or boat anglers for a given species on a sample day
$\hat{E}$ = estimated total angler effort (E_s, Equation 1, for shore angling; E_b, Equation 2, for boat angling)
$\hat{R}$ = estimate of catch-per-hour (C_s, Equation 5, for shore angling; C_b, Equation 4, for boat angling)

Harvest-per-hour and total harvest estimates for each angling mode are derived using the same analytical framework, with the exception that harvest (i.e. fish caught but not released) is substituted for catch. When calculating catch-per-hour or harvest-per-hour for each species recorded in the catch during the sample day, values for trip length (either mean, in the case of Equation 4, or individual, in the case of Equation 5) are held constant.

The incorporation of interviews obtained during ancillary surveys (i.e. boat angler interviews obtained during boat launch surveys and on-water surveys) that did not occur simultaneously with a bus stop creel poses a challenge, as it will require a departure from the standardized methodology described above. There are two potential approaches: 1) pool all interviews obtained over some time interval (e.g. a calendar week) and calculate a catch-per-hour specific to that time interval – this catch-per-hour estimate will then be substituted for $\hat{R}$ in equation 6 for all sample days that fall within that time interval; 2) pool all interviews obtained over some time interval, calculate a catch-per-hour estimate for that time interval ($\hat{R}$), and then multiply that catch-per-hour estimate by the sum of all angler effort for that mode within the time interval (i.e. $\hat{E}$ in equation 6 would represent the estimated sum of angler effort for the time interval, and $\hat{C}$ would be the estimate of total catch for that time interval). Both methodologies have potential drawbacks: using method 1 will artificially dampen within-stratum variance in catch, while method 2 will reduce overall sample size and associated statistical power when testing for within-year or across-year differences in angler catch. However, the catch estimates provided by either method are likely to be more accurate and precise than would be obtained by ignoring the substantial number of interviews obtained during ancillary surveys. Therefore, both methodologies will be applied and the results of each method will be considered with regards to relative benefits/drawbacks.

Estimation of Annual Angler Effort, Catch, and Harvest

The stratified calculation approach of Pollock et al. (1994) will be used to estimate total angler effort, catch, and harvest within a Season. These calculations will be performed separately for each angling mode (shore and boat). A stratified mean of each variable will be calculated for each mode (Pollock et al. 1994):

Seasonal Mean of Angler Effort, Catch, or Harvest (7)

$$\bar{y}_{st} = \sum_{h=1}^{L} W_h \bar{y}_h$$

where:
$\bar{y}_{st}$ = stratified mean of angler effort (E_s, E_b from Equation 1-2), catch ($\hat{C}$ from Equation 6), or harvest
W_h = weighting factor for stratum h = (total number of possible samples in stratum h) / (total number of possible samples in Season)
$\bar{y}_h$ = sample mean of angler effort, catch, or harvest for stratum h

The variance of the stratified mean is estimated as (Pollock et al. 1994):

Variance of Seasonal Mean of Angler Effort, Catch, or Harvest (8)

$$Var(\bar{y}_{st}) = \sum_{h=1}^{L} W_h^{2} \frac{S^2{}_h}{n_h} \left(\frac{N_h - n_h}{N_h} \right)$$

where:
$Var(\bar{y}_{st})$ = variance of the stratified mean of angler effort, catch, or harvest
W_h = weighting factor for stratum h (see Equation 7)
$S^2{}_h$ = sample variance of angler effort, catch, or harvest for stratum h
n_h = number of samples in stratum h
N_h = number of possible samples in stratum h

Total seasonal angler effort, catch, or harvest is then calculated as (Pollock et al. 1994):

Estimate of Total Seasonal Angler Effort, Catch, or Harvest (9)

$$\hat{Y}_{st} = N * \bar{y}_{st}$$

where:
$\hat{Y}_{st}$ = estimate of total angler effort, catch, or harvest for the Season
N = number of days in the Season
$\bar{y}_{st}$ = stratified mean of angler effort, catch, or harvest (Equation 7)

The variance of this seasonal estimate is calculated as (Pollock et al. 1994):

Variance of the Total Seasonal Estimate of Angler Effort, Catch, or Harvest (10)

$$Var(\hat{Y}_{st}) = N^2 Var(\bar{y}_{st})$$

where:
$Var(\hat{Y}_{st})$ = variance of the estimate of seasonal angler effort, catch, or harvest
N = number of days in the Season
$Var(\bar{y}_{st})$ = variance of the stratified mean of angler effort, catch, or harvest (Equation 8)

When calculating seasonal estimates of angler effort/catch/harvest, the number of days in the season (*N*, Equations 9-10) may be adjusted to account for days on which there was a high probability that no angling occurred (due to river flooding and/or inclement weather).

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