CORNELL UNIVERSITY AND NYSDEC

Evaluation of the NYSDEC Catch Rate Oriented Trout Stocking Program: Project Report

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Abstract

The recreational trout fishery in New York State annually generates millions of dollars in economic activity. Salmonids have been stocked in New York with the intent of enhancing this fishery since the 1860's. The NYSDEC's Catch Rate Oriented Trout Stocking (CROTS) model aims to provide anglers a high quality trout fishery and is based on several assumptions including natural mortality rate, angler effort, catch and harvest rate, as well as wild trout densities and carrying capacity. These CROTS parameters are largely derived from fieldwork conducted during the late 1970's. The objectives of this study were to evaluate several CROTS model assumptions, update the model to account for current conditions, and gain a better understanding of trout population dynamics and angler pressure patterns. Our findings indicate that, although several parameters of the CROTS model have changed significantly over the past three decades, the target mean catch rate of one fish per two hours of fishing has continued to be met. Relative to their previously estimated values, we observed an increased rate of natural mortality, a decrease in angler effort and a decrease in harvest rate. We updated the model and created a simple tool that can be used by managers to evaluate and revise stocking policies to better accommodate the contemporary fishery.

Introduction

Fish stocking is a popular, though controversial (Cambray 2003), and widely utilized fisheries management method intended to supplement populations in streams where natural reproduction cannot maintain a satisfactory fishery given the current level of recreational angling pressure (Hickley 1998). Members of the family Salmonidae, including trout, are among the most common species stocked in the USA. Proponents of supplemental trout stocking view the action as a means to provide angling opportunities and increase the number of fish that can be creeled in a stream while minimizing impacts to wild fish. Fisheries are often maintained with catchable sized hatchery fish in aquatic systems where native and naturalized fish populations cannot withstand the harvest demands of anglers (Epifanio and Nickum 1997). Stocking catchable sized hatchery trout can be used to conserve native or wild trout by directing consumptive angling to specific streams or stream reaches that are unproductive for native or wild trout, which can foster public acceptance of more restrictive regulations on native and wild trout waters (Van Vooren 1995). Furthermore, stocking can provide angling opportunities in waters where natural trout populations no longer exist due to anthropogenic impacts (Schramm and Mudrak 1994).

Opponents of supplemental stocking argue that potential benefits to anglers are outweighed by potential negative impacts to stream ecosystems and naturalized (wild) trout. Stocked fish have been shown to impact stream systems through several mechanisms including reduction of genetic diversity in wild fish populations (Leary et al. 1993), predation (Alexander 1977), competition and displacement of wild fish (Brooks et al. 2000; Dewald and Wilzbach 1992; Kerr and Grant 2000; Zimmerman and Vondracek 2007), disease transmission (Hulbert 1985), and hybridization (Sorensen et al. 1995). Public opinion is also divided on the issue, with some anglers preferring more wild trout fishing opportunities and others preferring put and take fisheries (Connelly and Brown 2009). Given the controversial nature of fish stocking within both fisheries management and the public, managers must be efficient, effective, and conservative when stocking trout into stream ecosystems.

Each year the NYSDEC stocks approximately 1.3 million catchable sized trout into over 4,600 km of streams in New York State (personal communication, Fred Henson, NYSDEC-Coldwater Fisheries Unit), often in sympatry with native trout and naturalized non-native (hereafter wild) trout, to provide a put and take fishery for recreational angling. Providing anglers with a satisfactory experience while minimizing the impacts of angling to native and wild trout populations is a primary goal of the NYSDEC trout stocking program. The NYSDEC has used an approach known at the Catch Rate Oriented Trout Stocking (CROTS) program for nearly three decades to establish trout stocking policies. The CROTS program guides selection of suitable streams for stocking and attempts to establish appropriate stocking levels in order to provide anglers an average catch rate of one fish every two hours for a defined portion of the fishing season (Engstrom-Heg 1990).

The CROTS program was first developed in the early 1980’s by NYSDEC biologist Robert Engstrom-Heg using evaluations of trout fishing regulations and biological data from stocked trout streams. Initially Engstrom-Heg (1990) provided a structural basis for a model that tracked stocked trout populations on a monthly basis throughout the fishing season. This structure was used to develop an interactive model called Trout.exe that tracks stocked trout populations on a daily basis, providing biologists with the ability to compare electrofishing abundance estimates directly with date-specific model trout abundance predictions (Treska 2005). These model predictions are specific to individual streams, enabling the CROTS program to provide stream specific stocking guidelines.

Many of the parameters used in the CROTS model have changed dramatically since previous estimates in the 1980's and 1990's (Figure 1; Table 2).The expense of hatchery trout production and lack of reliable persistence of stocked fish over the course of a fishing season provide the rationale to carefully evaluate the decision making process used in determining stocking locations, rates, and schedules. In order to determine whether the model and its parameter values are accurately depicting the actual trout populations covered by the CROTS program, it is necessary to perform evaluations of model predictions in relation to a collection of observed survey data (Treska 2005).

Based on findings from a collaborative study with Cornell University (Treska 2005, Sullivan and Kraft 2005), the NYSDEC identified the evaluation of CROTS model parameters as a high priority at a manager's meeting in 2009. The specific objectives identified were to:

1. Update our knowledge of trout population dynamics and fisheries.
2. Evaluate and update the CROTS model with more accurate estimates of model parameters.
3. Provide necessary tools to refine stocking rates and increase efficiency of trout stocking program.
4. Understand the differential harvest, mortality, and growth dynamics between age 1(SY) and 2 (2Y) year old stocked trout.

This study addressed the objectives outlined by the DEC and provided estimates of inter-annual, specific, and age differences in fish mortality, angler catch success and effort, and harvest. These parameter estimates will improve CROTS model stocking allocations and inform management. We also provide a user-friendly stocking model worksheet (Trout2014) that will allow regional biologists to accurately determine stocking locations, rates, and schedules. Additionally, through a series of collaborative meetings between Cornell University and NYSDEC biologists and managers, a suite of additional objectives were identified to improve parameter estimates and expand the model predictions. These "secondary" objectives include:

1. Modelling the influence of temperature and habitat variability on stocked trout mortality and abundance.
2. Investigating incomplete trip bias in angler creel surveys.
3. Optimizing creel survey duration.

This report begins by addressing our findings relating to the primary study objectives identified by the NYSDEC. We conclude the report with management recommendations and suggestions for future directions of study. This is followed by appendices (A-E) reporting our findings from secondary objectives as well as instructions for the Trout2014 program. It is our hope that this study will provide a rationale for updating and improving trout stocking in New York State and provide regional managers with necessary tools to make more informed fisheries management decisions.

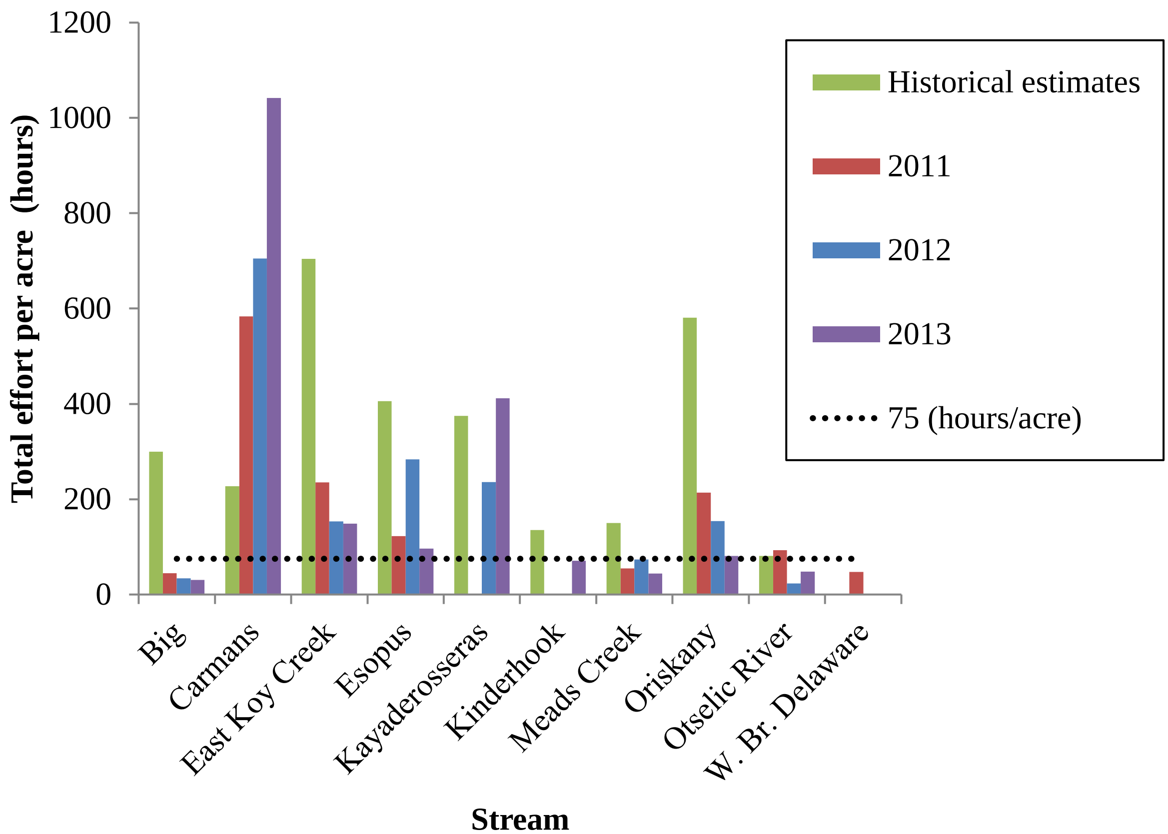


Figure 1. Angler pressure estimates (angler hours per acre) from historical creel surveys conducted in the 1980's and 1990's compared to estimates from this study in 2011-2013. Under CROTS guidelines, stocking is not generally advised for streams where angler pressure is less than 75 hours/acre. The Esopus data shown as from 2013 in this figure are from a creel survey completed in 2010 using the same methodology (see Table 2). Based on the availability of these data, the creel survey was not included in the 2013 workplan and the 2010 data were used instead. Carmans River effort in 2013 was 633 hrs/acre (Table 2) disregard display error in this figure.

General Approach

We conducted creel surveys and fish population estimates in nine streams across New York State (see map below; Table 1) from 2011 to 2013. Streams and reaches were selected by NYSDEC regional biologists based on their representativeness of regional streams and the availability of historical creel and population estimate data. The original intent was to have an even number of A (higher quality trout fishery based on intensity level of angling and streams' ability to sustain trout) vs. B streams (lower quality trout fishery based on intensity level of angling and streams' ability to sustain trout), however, logistical difficulties led to the ratio being seven A streams to two B streams. The entire stocked area of each stream was surveyed by a creel agent for the duration of the fishing season. Trout stocked in the study streams were fin clipped according to their age (1Y or 2Y), species, increment of release (April-June), and year (2011-2013). The study streams were stocked exclusively with Rome strain domestic brown trout except for the Carmans River where domestic rainbow trout constituted 50% of the annual total.

Detailed operational protocols for each of the activities described above were developed and approved by a project committee composed of Cornell and NYSDEC biologists (Appendix F). NYSDEC staff were responsible for completing fieldwork according to these protocols and providing data in standardized formats to facilitate analysis by the authors.

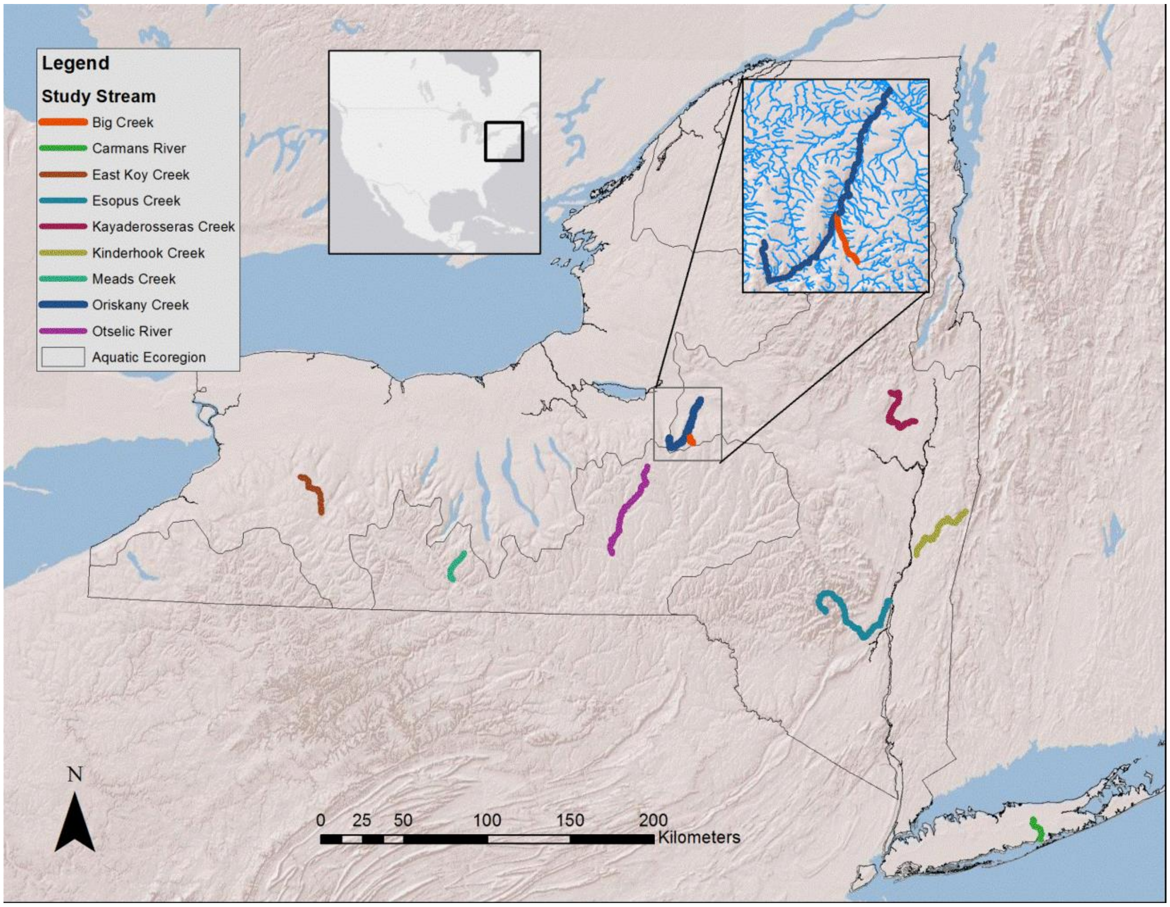
Table 1. Study stream characteristics.

Stream Name	CROTS (A/B)	Stocked Area (acres)	Trout stocked annually	Region
Big Creek (BIG)	A	18	2700	6
Carmans River (CAR)	A	12	1860*	1
East Koy Creek (EKY)	A	50	11897	9
Esopus Creek (ESP)	A	30	4438	3
Kayaderosseras Creek (KAY)	A	33	4320	5
Kinderhook Creek (KIN)	A	34	4640	4
Meads Creek (MDS)	B	36	3137	8
Oriskany Creek (OKY)	A	63	17690†	6
Otselic River (OTS)	B	94	14703	7

* Annual total comprised of 50% brown trout and 50% rainbow trout

† this total includes fall-stocked fingerlings, total number of yearling and older trout stocked in Oriskany creek given in table 4.

Map 1. Map of study streams for evaluation of CROTS model parameters.



Parameter Estimates

Creel Survey

Methods

With the exception of the Carmans River, where the existence of a fenced park boundary permitted an access point survey design (Pollock et al. 1994), roving creel surveys were conducted on all waters in the study. Roving creel survey results were based on instantaneous vehicle or angler counts and on-stream angler interviews. Surveys ran either three months (April – June) for "B" streams or the full season (April 1 – October 15) for "A" streams. Survey days were stratified by weekend days and weekdays. Holidays were included with weekend days.

The fishing day was defined as sunrise to sunset, and two secondary sampling units (work periods) were defined for each day. Early (morning) or late (afternoon) starting times, locations, and direction of travel were randomly chosen for each survey. Each survey day began with an instantaneous count. In the case of Esopus Creek, suitable vantage points and clear sight lines allowed for an instantaneous count of actual anglers but, in all other roving creels, parked vehicles were counted and these counts were used to estimate angling effort as described below. Numbers of vehicles were recorded on count forms designed for the needs of each stream. At each access site, clerks counted the number of vehicles, interviewed anglers, and placed postage-paid self-addressed recreational survey cards on all parked vehicles. If time allowed in the survey set up, two subsequent vehicle counts were conducted. One count began three hours after the conclusion of the first count and then another three hours after the conclusion of the second count. Between vehicle counts, the clerk interviewed anglers based on methodology outlined by Malvestuto (1996). Biological data collected from fish captured by anglers included the total number of trout caught by species, number of trout creeled, number of trout released, and lengths of the trout (either measured for creeled trout or estimated for released trout). For creeled trout, the clerk examined each fish visually and checked for the presence of fin clips to determine whether the fish was of wild or hatchery origin and what stocking increment it came from.

The hours of fishing effort were estimated from vehicle counts as follows: estimated total party hours (ETPH) were derived from instantaneous arrival and departure counts of parked vehicles at access sites. We adjusted ETPH estimates that included stream users who were not fishing by multiplying ETPH by the average number of anglers per vehicle (this step could be omitted in the case of Esopus Creek where anglers were counted directly). The resulting product represented an estimate of the number of angler hours during the creel day (estimated total angler hours, ETAH). This estimate includes time spent by anglers fishing and doing other activities (e.g., swimming, camping). To obtain an estimate of actual fishing hours, we adjusted ETAH by a fishing ratio correction factor. This ratio was estimated by dividing the average length of time spent fishing by the total length of time at the stream. The resulting product estimated the actual number of fishing hours during the creel day (estimated total fishing hours, ETFH).

Using data collected from the creel surveys, angler effort (hours/acre), harvest rates, and catch per unit of effort were estimated using methods outlined in Pollock et al. (1994). Daily effort (e_i) was estimated as

$$e_i = I_i \, x \, T,$$

where I_i is the instantaneous count of anglers at *time* $_i$, and T is the length of the fishing day. Total effort for the survey period was estimated as:

$$E = \Sigma(e_i/\pi_i),$$

Where π_i is the total probability that the ith sample unit (day) is included in the sample (month). CPUE (R) was estimated using the mean of ratios (i.e., the average of individual catch rates) for incomplete trips:

$$R = \Sigma\ (c_i/L_i)/n,$$

where *ci* is the catch for *i*th sampling unit and L_i is the length of the fishing trip at the time of the interview (incomplete trip), and *n* is the number of sampling units in the sample. Finally, total catch (C) was estimated as:

$$C = E \, x \, R.$$

Total harvest and harvest rate (HPUE) were calculated using the same methods as above for fish that were kept in the creel. We also estimated the number of stocked fish only (i.e., excluding wild fish) harvested using the same methods. We analyzed differences in catch, harvest, and mortality rates using a one-way analysis of variance (ANOVA). Inter-annual, species, age, and stream differences were also analyzed using a one-way ANOVA. Interactions among variables were examined using a factorial ANOVA. Where data did not meet normality assumptions, we used a Kruskal-Wallis one-way ANOVA on ranks. We employed a Tukey test when homogeneity of variance assumptions were not met.

Results

Angler effort (P=0.006) (Figures 2-4) and total catch (P=0.025) differed significantly between streams, but catch per unit of effort (CPUE) did not differ from the CROTS target rate of 0.5 fish/hour (P = 0.21) (Figures 5-7). Total season effort (hours/acre) was significantly different from historical CROTS estimates for all years in the study (P= 0.003) when averaged together, though not between study years (P=0.994); though the Kayaderosseras had similar effort levels to previous study years. Harvest or creel rate (Pk) differed significantly from the CROTS assumed rate of 1.0 (P<0.001) (Figures 8-9). Consequently, the estimated mean number of stocked trout harvested each year during the fishing season was quite low for all streams ranging from 9 to 608 harvested fish (Table 3). “A” streams did not significantly differ from B streams for total monthly effort (P= 0.278) or effort in hours per acre (P= 0.090). There was not a significant difference between A and B stream CPUE (P= 0.762) or total catch (P=0.216). We suggest using caution when interpreting "not significant" results from the creel surveys due to lower than desired power levels of 0.80 for all analyses, indicating that we are less likely to detect a difference when one actually exists.

Interpretation

The observations from the creel surveys revealed some interesting patterns and major deviations from assumed and historical values previously used in the CROTS model. These changes will have major ramifications for CROTS model predictions. The most pronounced difference was the change in Pk from the assumed rate of 1.0. While there was variation in Pk between streams in the study, all streams showed significantly lower Pk rates than 1.0 in all years of the study. Based on our findings, assuming a Pk of 0.20 to 0.30 in the absence of creel survey data for a stream might be more reasonable than assuming a Pk of 1.0. Even when the Carmans River was removed from the analysis, the remaining streams averaged a Pk of .30, indicating this finding was not driven by a single outlier stream. This finding might have repercussions for catch limits and other harvest regulations.

An unintentional consequence of the rise of catch and release angling is the difficulty it creates for collecting biological data through creel surveys. Since most fish are released before the creel agent is able to interview the angler, the agent relies on angler reporting rather than actually confirming the data themselves. This type of data collection is similar to an angler diary program that, while useful, has inherent limitations. For example, because the creel agent only handled a small portion of fish and anglers did not generally notice or recall whether or how the trout that they release were marked, we were unable to parse out catch differences between one and two year old fish. Alternative methods for collecting catch data might be more cost effective and yield similar data.

The pronounced decrease in estimated total angler effort hours and effort hours per acre from historical estimates is also particularly noteworthy. Only two streams, the Carmans[‡] and Otselic had angler effort levels comparable or higher than estimates from the 1980's and 1990's. The remaining six streams had substantially lower angler effort levels than expected, indicating that some of these streams might require re-designation of intensity level in the CROTS model.

[‡] Results from Carmans River creel survey should be interpreted cautiously, especially when compared to other streams in the study because different survey methods were employed (access survey).

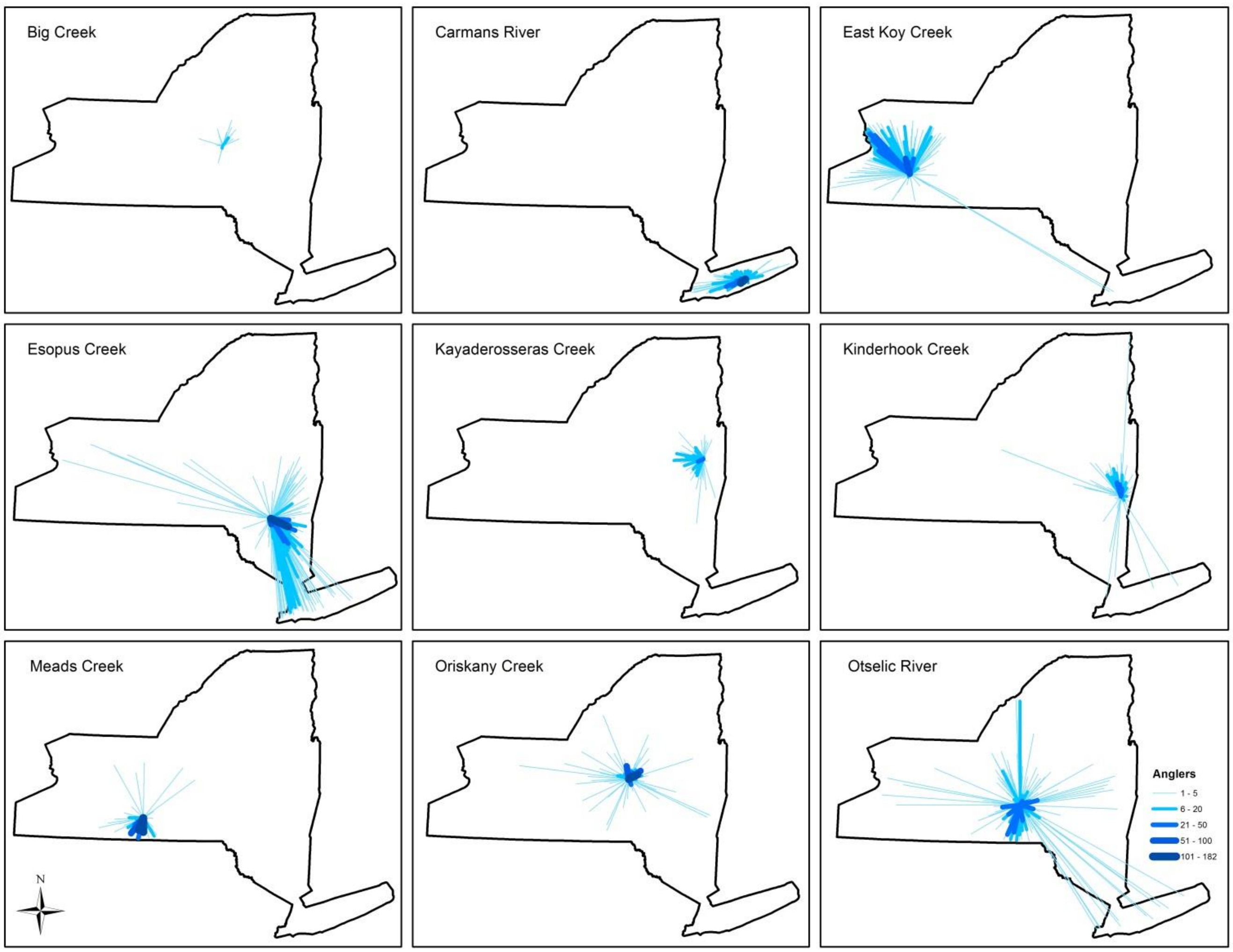
Interestingly, the suggested assumed intensity level in CROTS for streams without creel information is 150 hours per acre, while the median intensity level for this study was 154 hours per acre, confirming the CROTS assumption.

Angler Characteristics

In addition to questions about effort and harvest, creel agents also asked anglers for demographic information. Questions covered a range of topics including gear type, home zip code, and, for the final year of the study, the decade in which they were born. The aim of this portion of the study was to gain an understanding of the "typical" NY trout angler, and, if regional variation was detected, explore links between those differences and the fishery.

Gear type fell into three broad categories: bait, lure, and fly fishing, with some anglers using a combination of types within a single fishing section. All gear types were legal in the study streams, with the exception of Carmans River which has a fly-fishing-only section (see Appendix G for full list of angling regulation for each study stream during study period). In general the majority of anglers in the streams fished using bait, sometimes in conjunction with lures, while pure lure and fly fishing was somewhat less popular (10-30%) (Figure 10). Unlike bait and lure fishing, fly fishing was rarely combined with other angling styles. The only stream to show a major deviation from this pattern was Carmans River where more than 80% of anglers fly fished, likely due to the previously mentioned regulations. Fly fishermen were also more likely to release fish than either bait or lure anglers (Figure 11) which may help explain the high release rates for Carmans River (Figure 9).

Approximate angler age was calculated from the birth decade question asked by creel agents by assuming a birth year in the middle of the decade and subtracting that year from the study year. Using this approximation we found no major differences in angler age among study streams, although the median age at Meads Creek, Oriskany Creek, and Otselic River was one decade lower than the other study streams (Figure 12). This is interesting as it includes both B-streams, suggesting that older anglers may preferentially choose streams with better trout habitat. The median age of fly fishermen was a decade older than bait and lure fishermen, which may be due to older anglers having more time to attain the skill and specialization necessary to successfully employ the technique (Figure 13). A comparison of age and CPUE showed no significant difference in catch-rate between anglers aged 15-75, but that anglers outside of that range seemed to have slightly lower catch-rates (Figure 14). This may, however, be due to the small sample size within those age ranges. There were no discernible patterns in angler age across the season (Figure 15). This challenges the idea that stocking trout produces an influx of young anglers eager to take advantage of the higher fish density immediately post-stocking. Finally, examination of zipcode data provided by anglers indicated major variation in the distance traveled by anglers to a particular stream, as shown in Map 2. East Koy and Esopus creeks appeared to draw in the most anglers from far areas. Surprisingly, the Otselic appeared to also bring in anglers from distant locations, as it is a designated “B” stream.



Map 2. Distances traveled by anglers to study stream from 2011-2013 (Note that Kayaderosseras only includes anglers from 2012-2013 and Kinderhook was limited to 2013). Thick lines indicate more anglers, thin lines indicate fewer.

Table 2. Estimated total effort (hours), catch per unit of effort (CPUE) (trout/hour) and effort/acre for 2011-2013. (Note that estimates from 2011 creel survey on the West Branch of the Delaware are included in table for reference purposes only; the stream was not included in the overall study). Most recent prior estimates of effort (italicized) provided for comparison. Use of the annual average CPUE to calculate total catch and harvest tends to overestimate these statistics relative to calculating them on a monthly basis and summing the monthly results. The extent of the difference between the results of the two calculation methods depends on the extent of the variability in effort and catch rate over the course of the fishing season.

Year	Stream	Effort	Mean catch rate	Acres	Effort(hrs/acre)
1978	Kinderhook	na	na	na	*138*
1986	W. Br. Del.	na	na	na	*100*
1989	Kayaderosseras	na	na	na	*375*
1990	Esopus	na	na	na	*406*
1991	Meads	na	na	na	*150*
1995	Carmans	na	na	na	*227*
1996	Big	na	na	na	*300*
1996	Oriskany	na	na	na	*581*
1996	Otselic	na	na	na	*81*
1998	East Koy	na	na	na	*704*
2010	Esopus	2901	0.44	30	97
2011	Big	808	1.53	18	45
2011	Carmans	7002	1.14	12	584
2011	East Koy	11769	0.71	50	235
2011	Esopus	3675	0.72	30	122
2011	Kayaderosseras	na	na	na	na
2011	Kinderhook	na	na	na	na
2011	Meads	1982	0.28	36	55
2011	Oriskany	13475	1.14	63	214
2011	Otselic	8747	0.81	94	93
2011	W. Br. Del.	9336	0.53	196	47
2012	Big	609	0.66	18	34
2012	Carmans	8457	1.59	12	705
2012	East Koy	7678	0.81	50	154
2012	Esopus	8511	0.81	30	284
2012	Kayaderosseras	7797	0.44	33	236
2012	Kinderhook	na	na	34	na
2012	Meads	2650	0.25	36	74
2012	Oriskany	9708	0.99	63	154
2012	Otselic	2181	0.51	94	23

Year	Stream	Effort	Mean catch rate	Acres	Effort(hrs/acre)
2013	Big	556	0.45	18	31
2013	Carmans	7593	1.53	12	633
2013	East Koy	7425	0.89	50	149
2013	Kayaderosseras	13578	0.62	33	411
2013	Kinderhook	2414	0.42	34	71
2013	Meads	1593	0.42	36	44
2013	Oriskany	5096	0.84	63	81
2013	Otselic	4542	0.33	94	48

Table 3.Summary of estimated annual total number of stocked trout harvested in each study stream.

Stream	2010	2011	2012	2013
Big	na	111	219	28
Carmans	na	9	19	23
East Koy	na	295	245	191
Esopus	63	50	184	na
Kayaderosseras	na	na	88	197
Kinderhook	na	na	na	100
Meads	na	63	55	19
Oriskany	na	608	444	136
Otselic	na	382	48	72

Table 4. Annual average of total number of yearling and older trout stocked (actual), total trout caught (expanded estimate) and total trout creeled (expanded estimate). Estimates of total trout caught and creeled include both stocked and wild fish.

Stream	Number of trout		
	Stocked	Caught	Creeled
Big	2700	1405	421
Carmans	1860	6412	169
East Koy	11897	8694	2608
Esopus	4438	3444	1033
Kayaderosseras	4320	6343	1269
Kinderhook	4640	1134	340
Meads	3137	851	255
Oriskany	9690	12389	4955
Otselic	14703	3575	1788

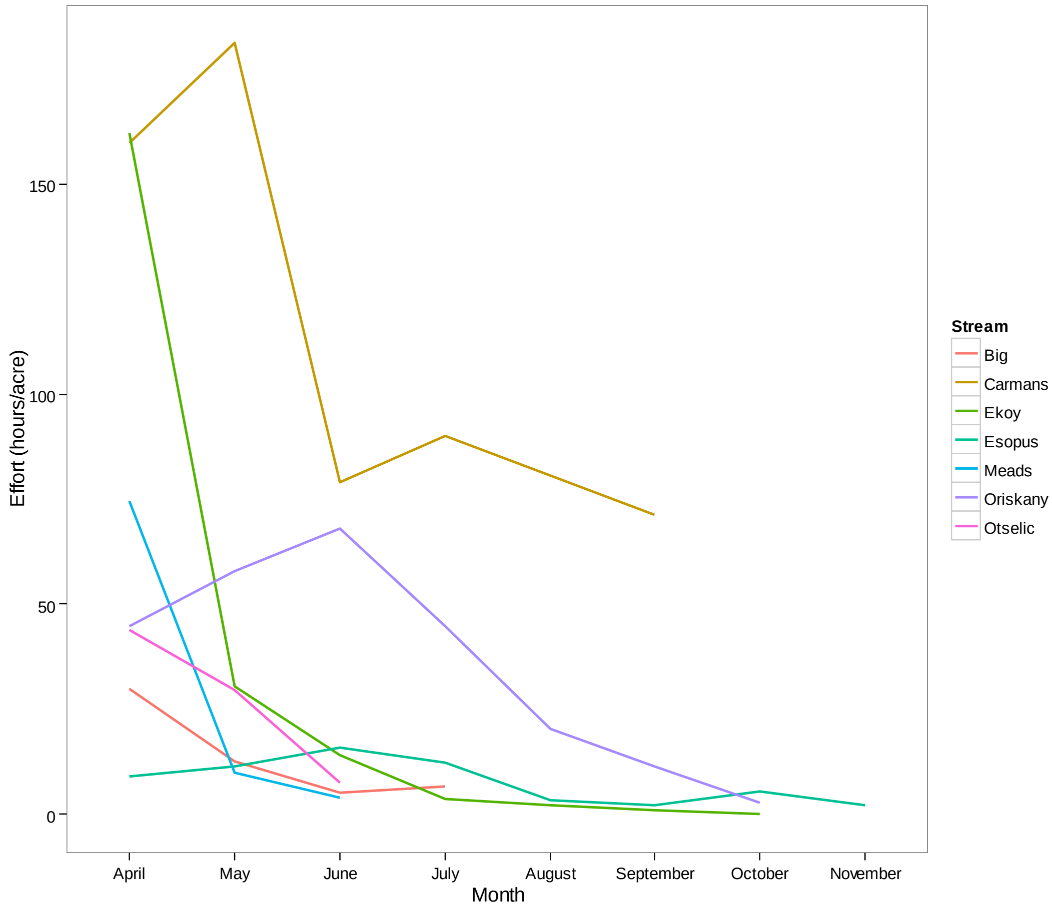


Figure 2. 2011 Total angler effort per month (hours/acre).

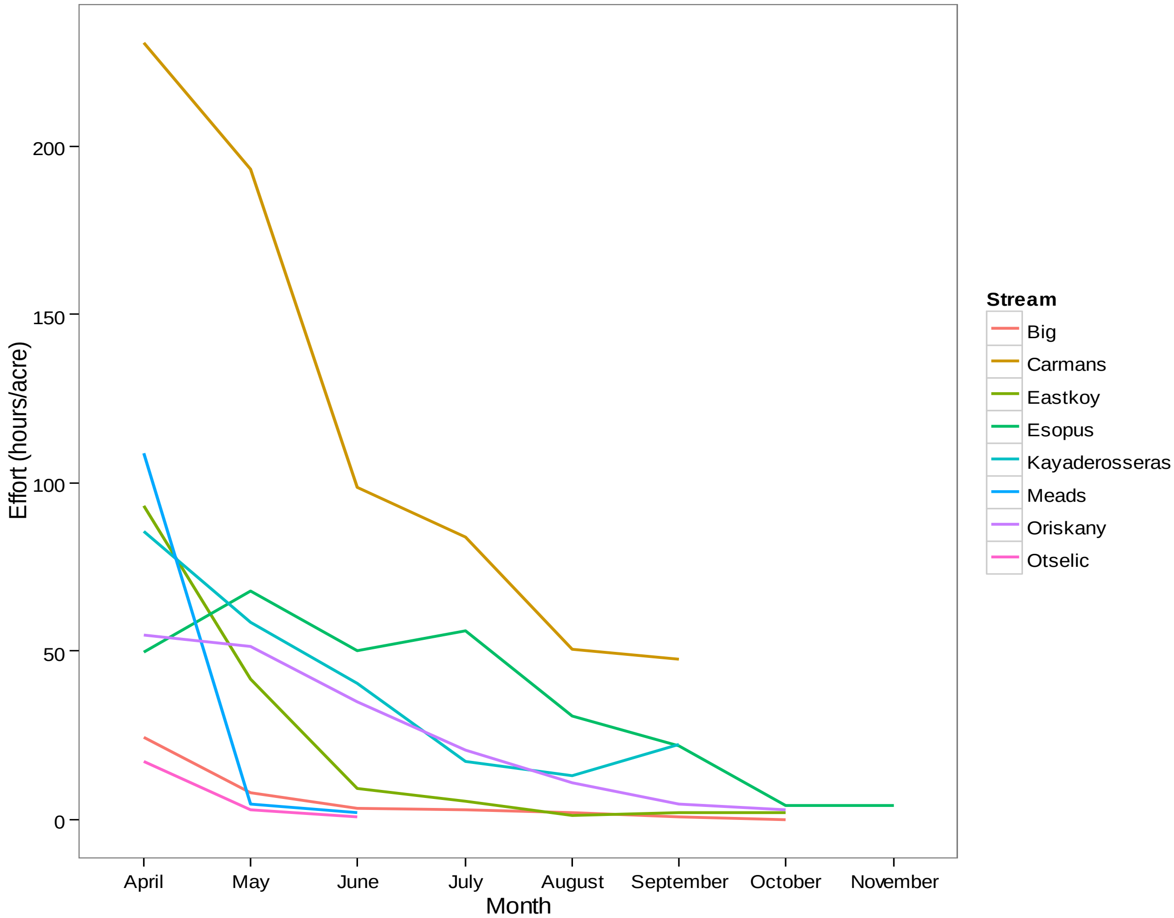


Figure 3. 2012 Total angler effort per month (hours/acre).

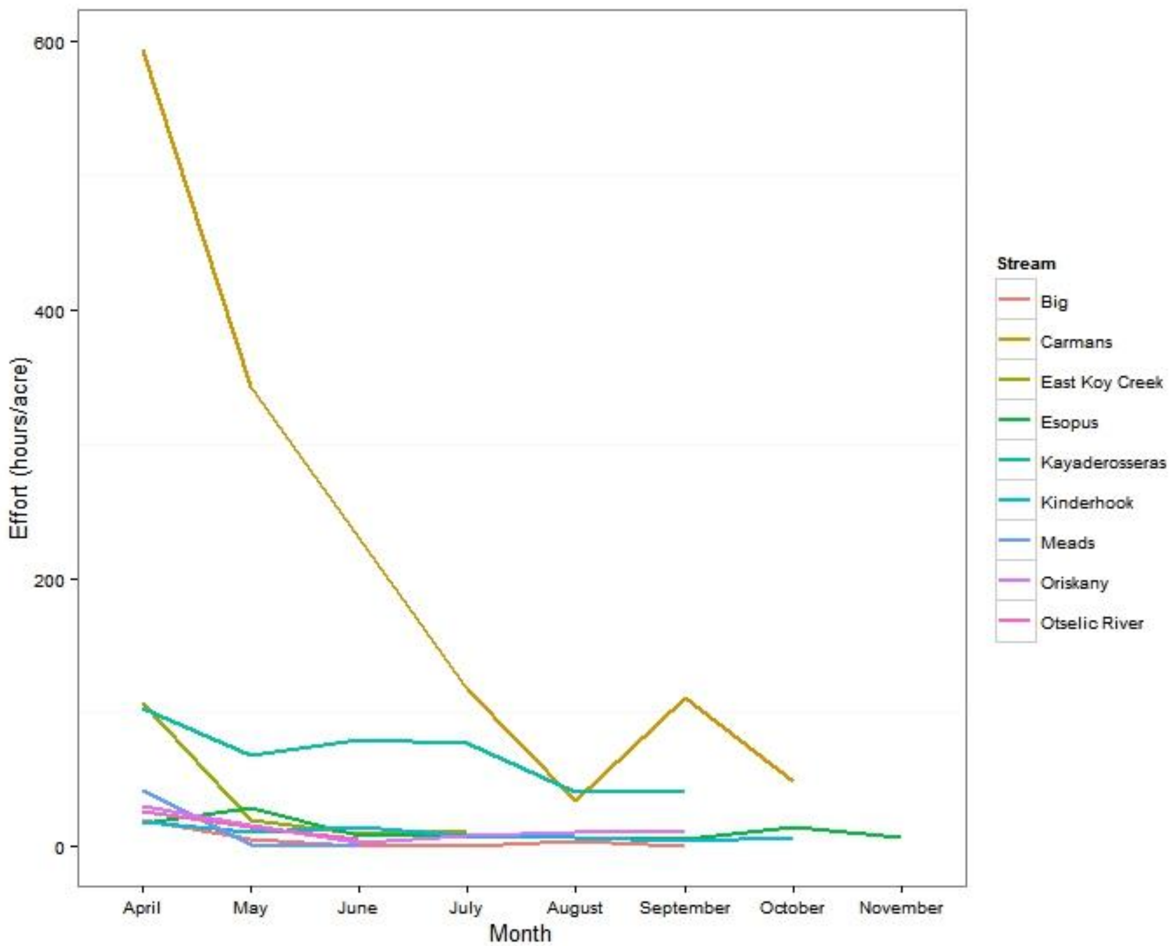


Figure 4. 2013 Total angler effort per month (hours/acre). The Esopus data shown in this figure are from a creel survey completed in 2010 using the same methodology. Based on the availability of these data, the creel survey was not included in the 2013 workplan. The 2010 Esopus Creek creel data are included with the 2013 creel data from the other streams strictly for convenience and should not be used for intra-annual comparison. Erratum: Disregard Carmans River effort in <u>this</u> figure – correction made to Table 2.

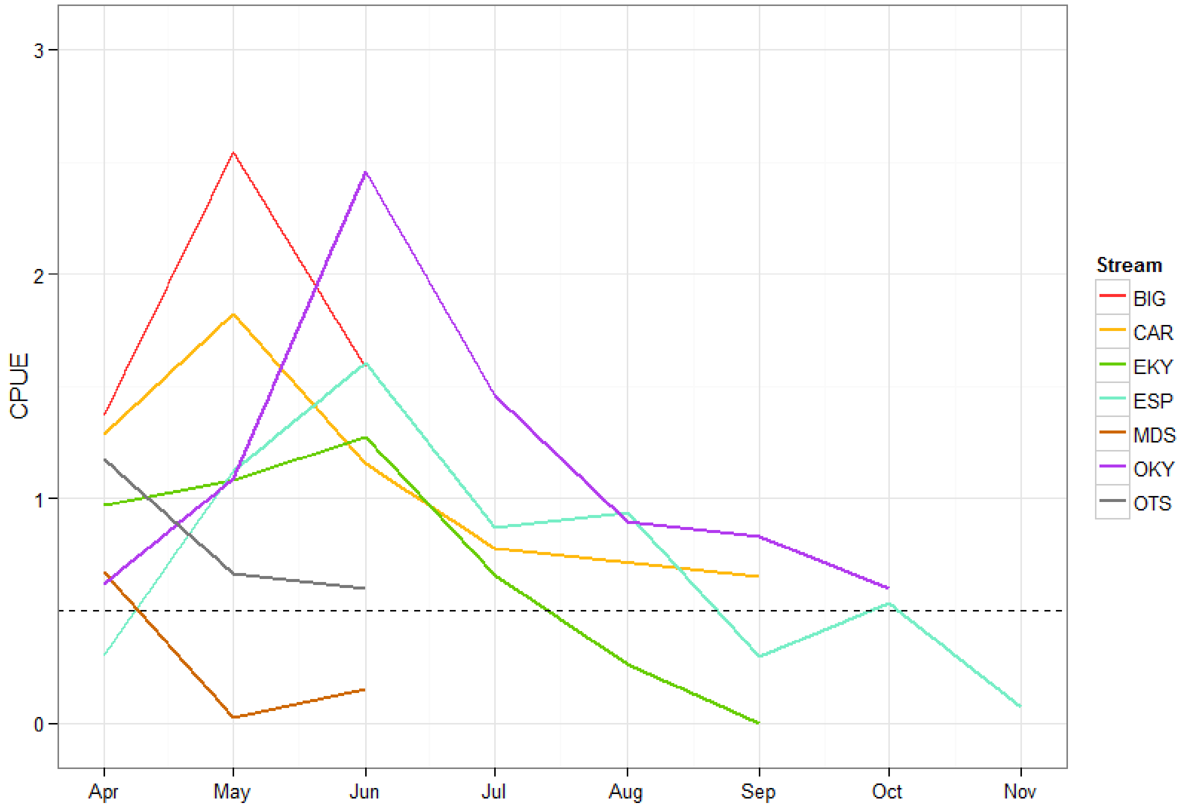


Figure 5. 2011 Mean monthly catch per unit of effort

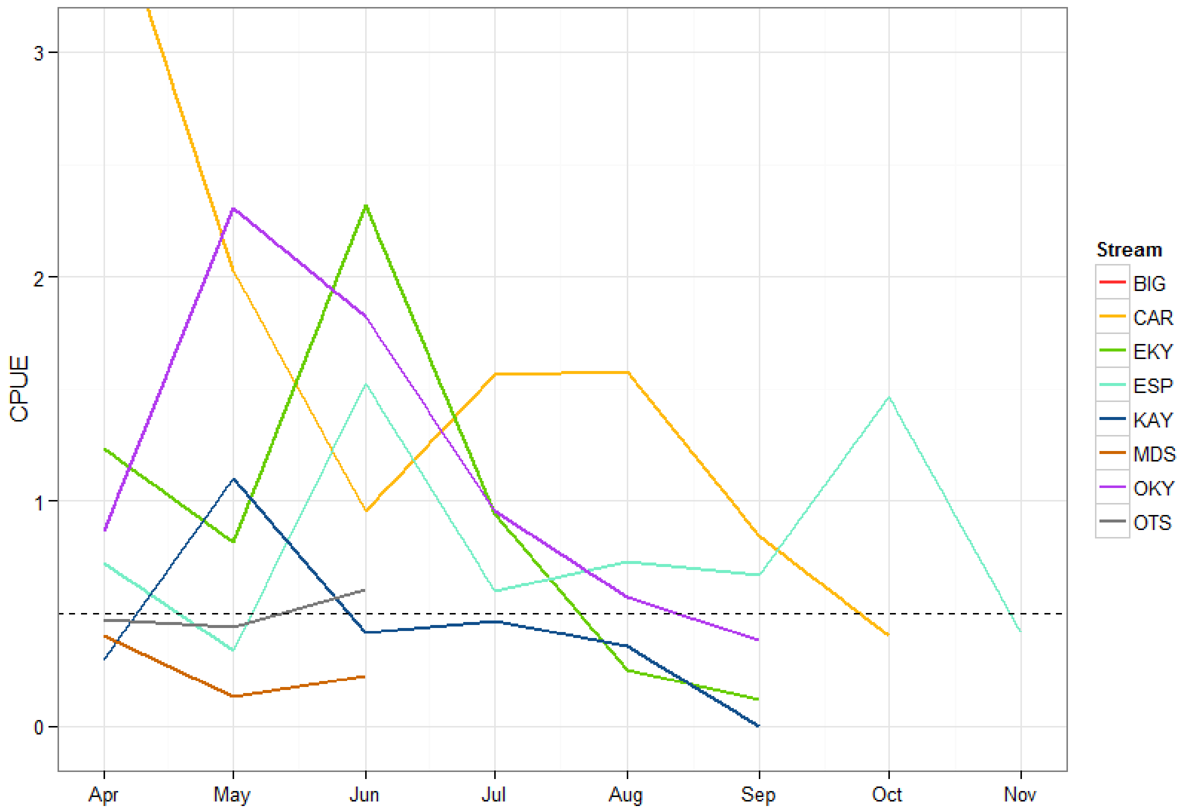


Figure 6. 2012 Mean monthly catch per unit of effort (absence of an estimate for Big Creek due to lack of sufficient data to calculate a monthly estimate).

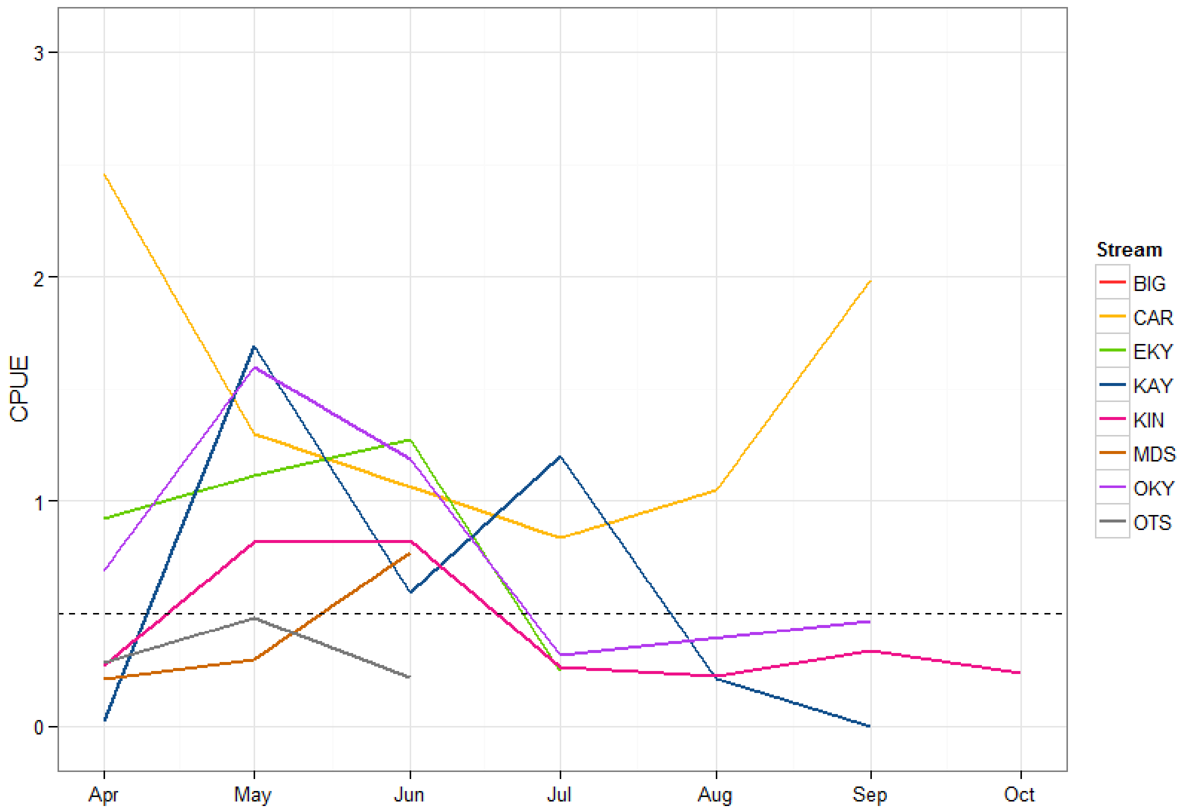


Figure 7. 2013 Mean monthly catch per unit of effort (absence of an estimate for Big Creek due to lack of sufficient data to calculate a monthly estimate). Erratum: Disregard Carmans River CPUE in this figure – correction made to Table 2.

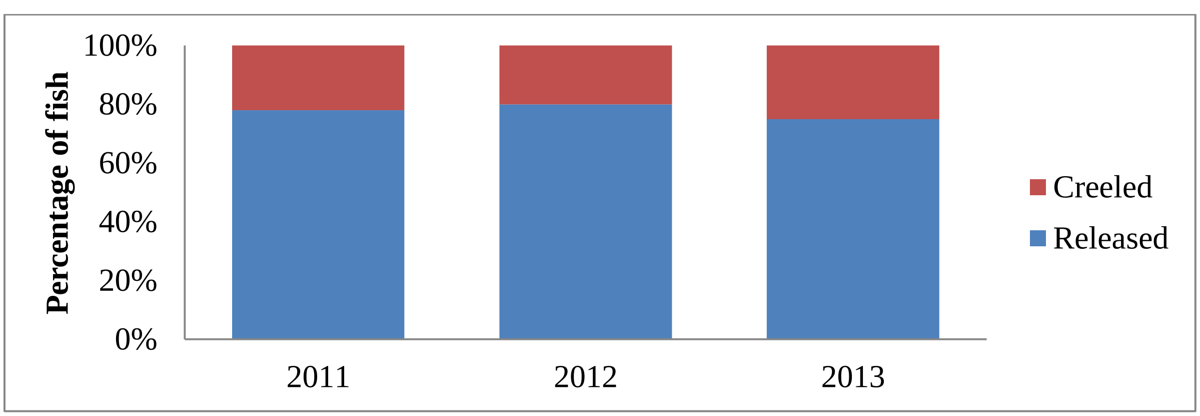


Figure 8. Average proportion of trout creeled (Pk) vs. released for all study years.

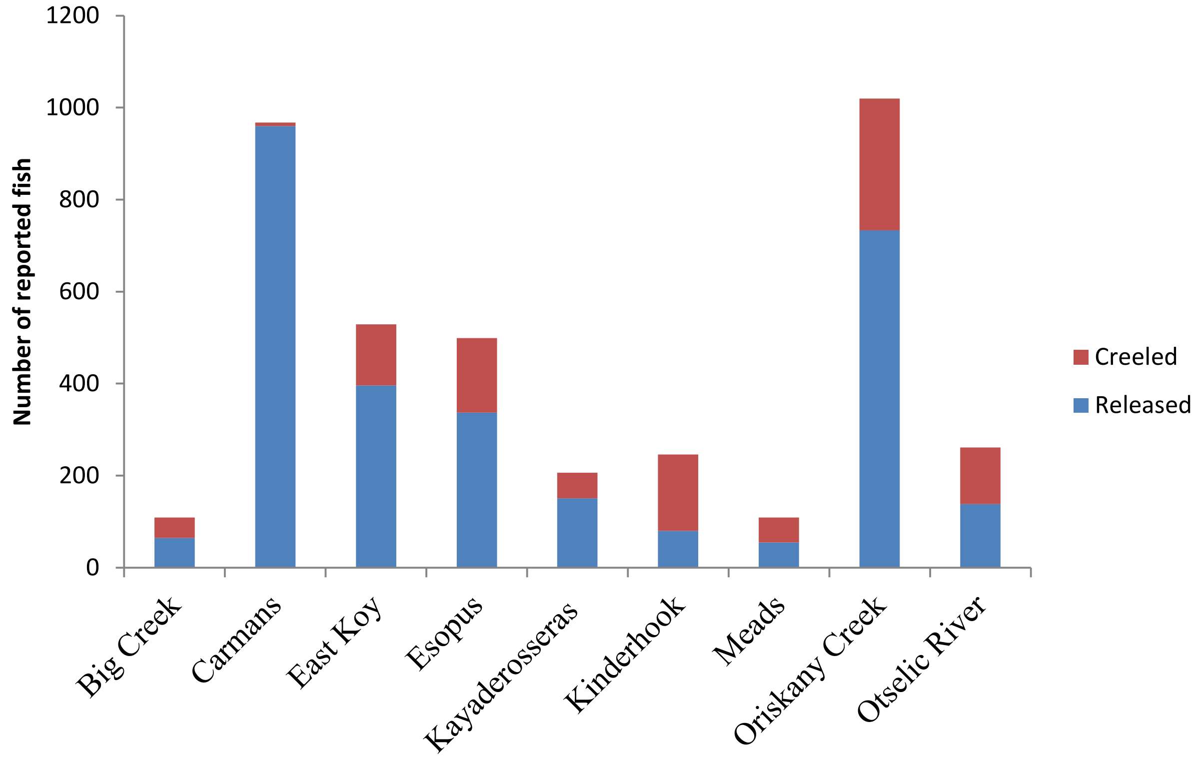


Figure 9. Actual proportion of trout creeled (Pk) vs. released for each stream in the study averaged over the three study years (2011-2013).

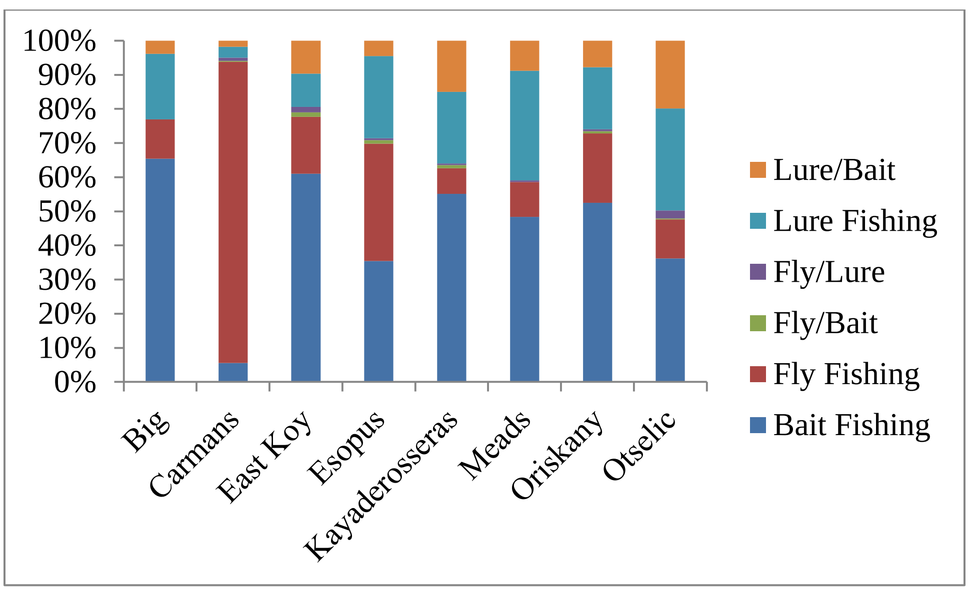


Figure 10. Percentage of anglers using each surveyed gear type, by stream over the study period.

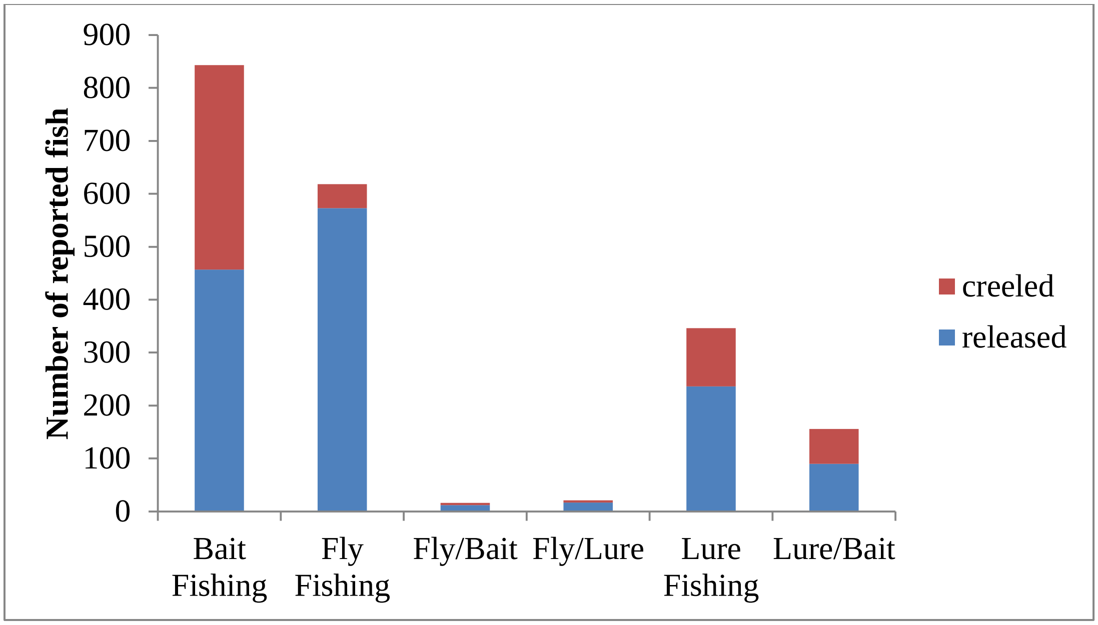


Figure 11. Creel rate, by gear type

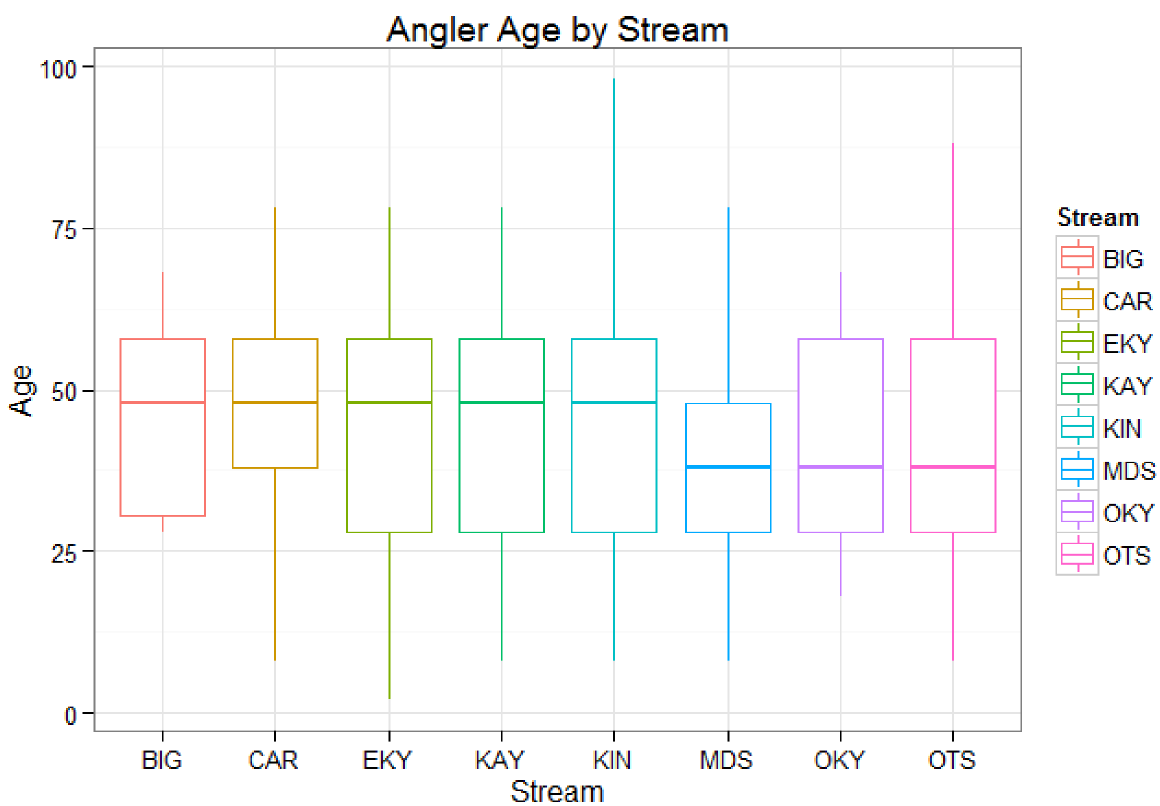


Figure 12. Distribution of approximate angler age by stream for 2013

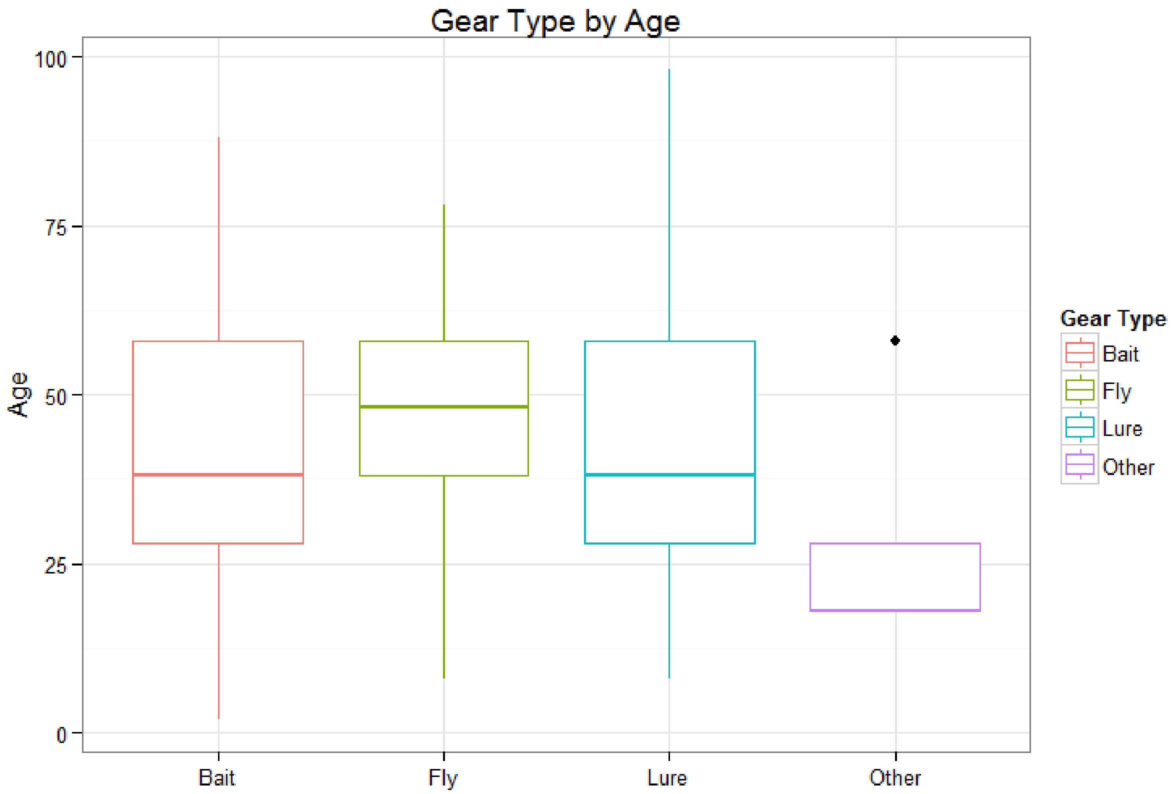


Figure 13: Distribution of approximate angler age by gear type for 2013

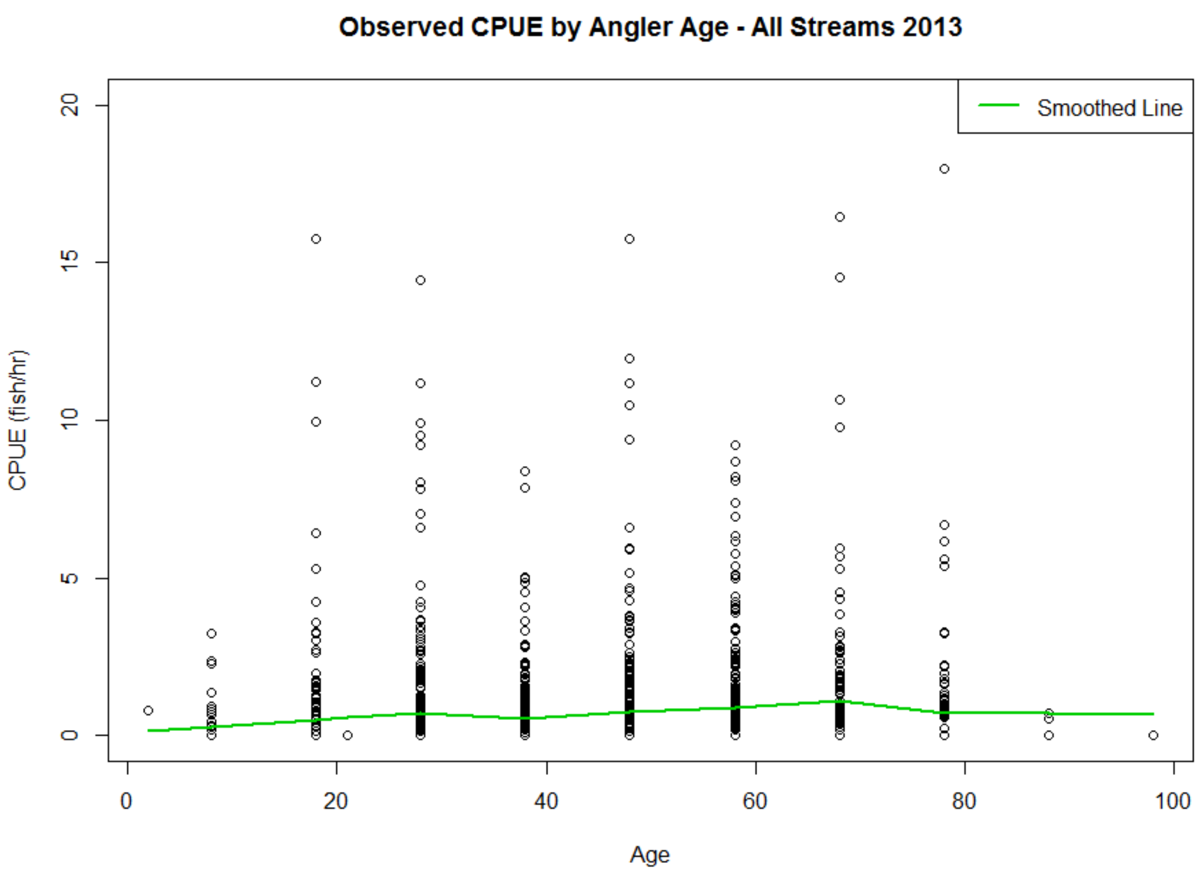


Figure 14. Catch rate by angler age across all streams with a smoothed line

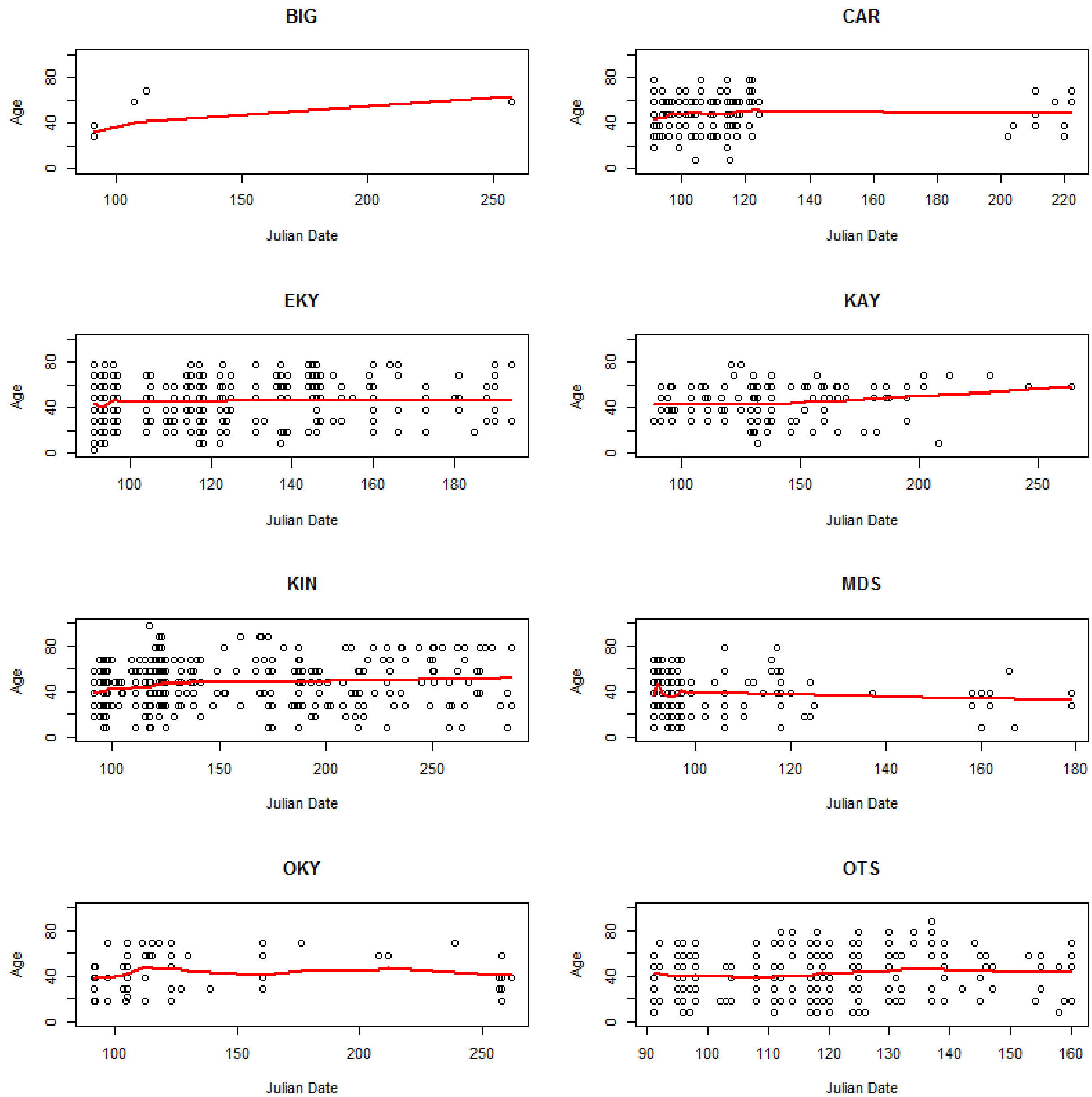


Figure 15. Patterns in angler age across the 2013 fishing season for all streams with a smoothed line fitted to show central tendency

Population estimates

Methods

Subsequent to stocking, two electrofishing population estimates were made on the study reaches. Sites selected for electrofishing were reasonably proximal to stocking locations and representative of both the habitat and the angling effort within the study reach. The minimum recommended reach length was 100 m in streams <10 m mean wetted width. In streams with mean wetted widths exceeding 10 m, the minimum recommended length was 200 m. In all cases, electrofishing effort consisted of three passes, where the stream section sampled was isolated during the sample using blocking seines or natural features (shallow riffles) to approximate a closed population compatible with a depletion estimate. The initial assessment was made within two weeks of the first increment of stocking when possible. When this objective could not be met, the initial estimate was conducted within two weeks of the second stocking increment, though this objective could not always be met due to continual high flows in 2011 and 2013. The second assessment was made between mid-June and mid-July for B streams and between mid-July and the end of August for A streams. One electrofishing unit (barge wand/ backpack shocker) was employed per 3m of mean stream wetted width (e.g., 3 wands in a 9-11m mean wetted width 4 wands in a 12m stream, etc.) to ensure standardized surveys across all streams. A Leslie-Delury Binomial model was used to estimate abundance from the three pass depletions.

Results

There were steep declines in fish densities shortly after stocking, indicating high total apparent mortality of fish (see Natural Loss section below) (Figure 16a). These declines represent a rapid loss of fish from the stocked reach. There appears to be a significant difference between annual mean densities of stocked trout (densities averaged from both sampling occasions each year) ($P=0.004$). However, these differences are difficult to interpret because the timing of surveys varied from year to year as episodic flooding and high flows necessitated the modification of survey schedules to avoid working in unsafe conditions. The extent of inter-annual variation in hydrologic conditions is well illustrated by the deviation from the average monthly precipitation for the three study years (Figures 16 b,c,d). The mean capture probability for all streams over the course of the study was 0.69, with capture probability improving each year in the study.

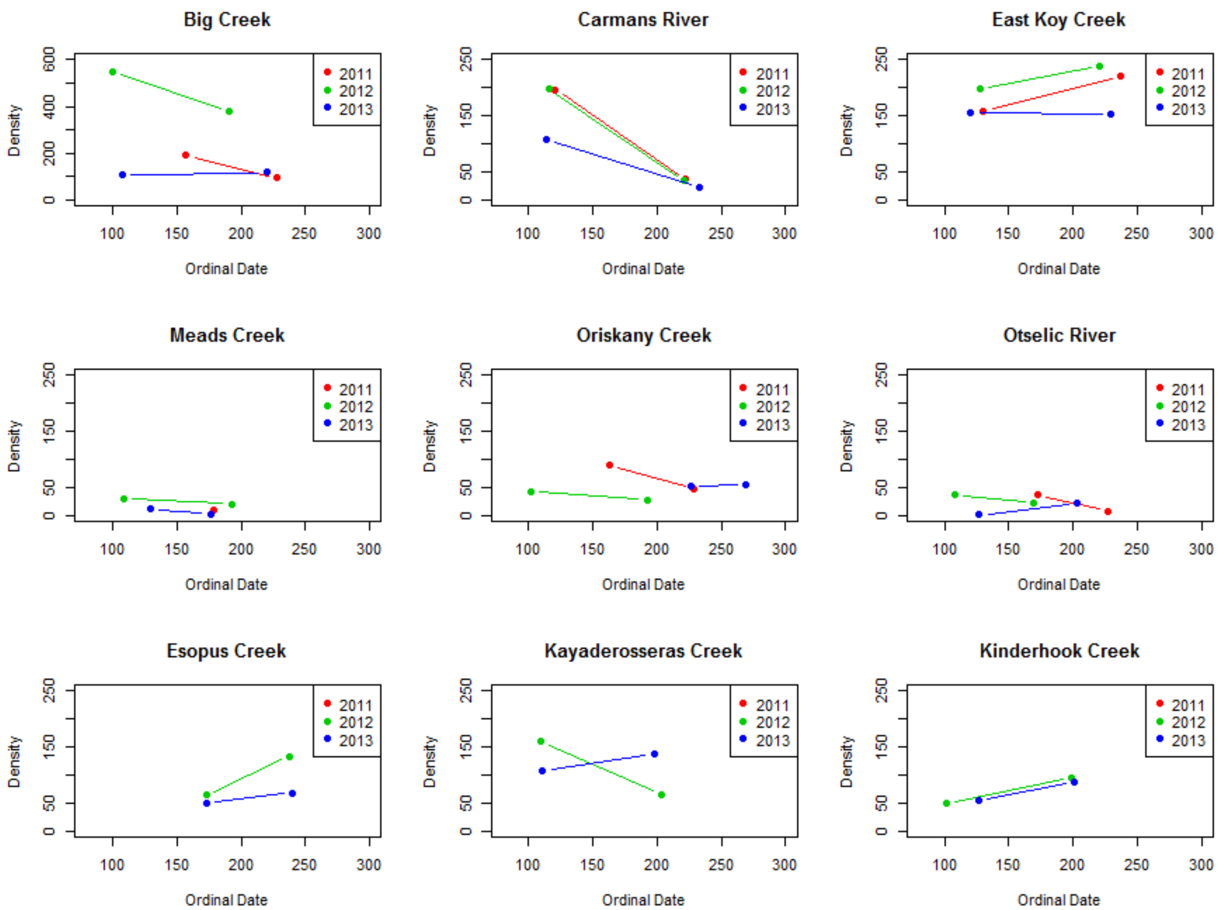


Figure 16a. Observed densities for trout of all species (trout/acre) during spring and fall electrofishing surveys.

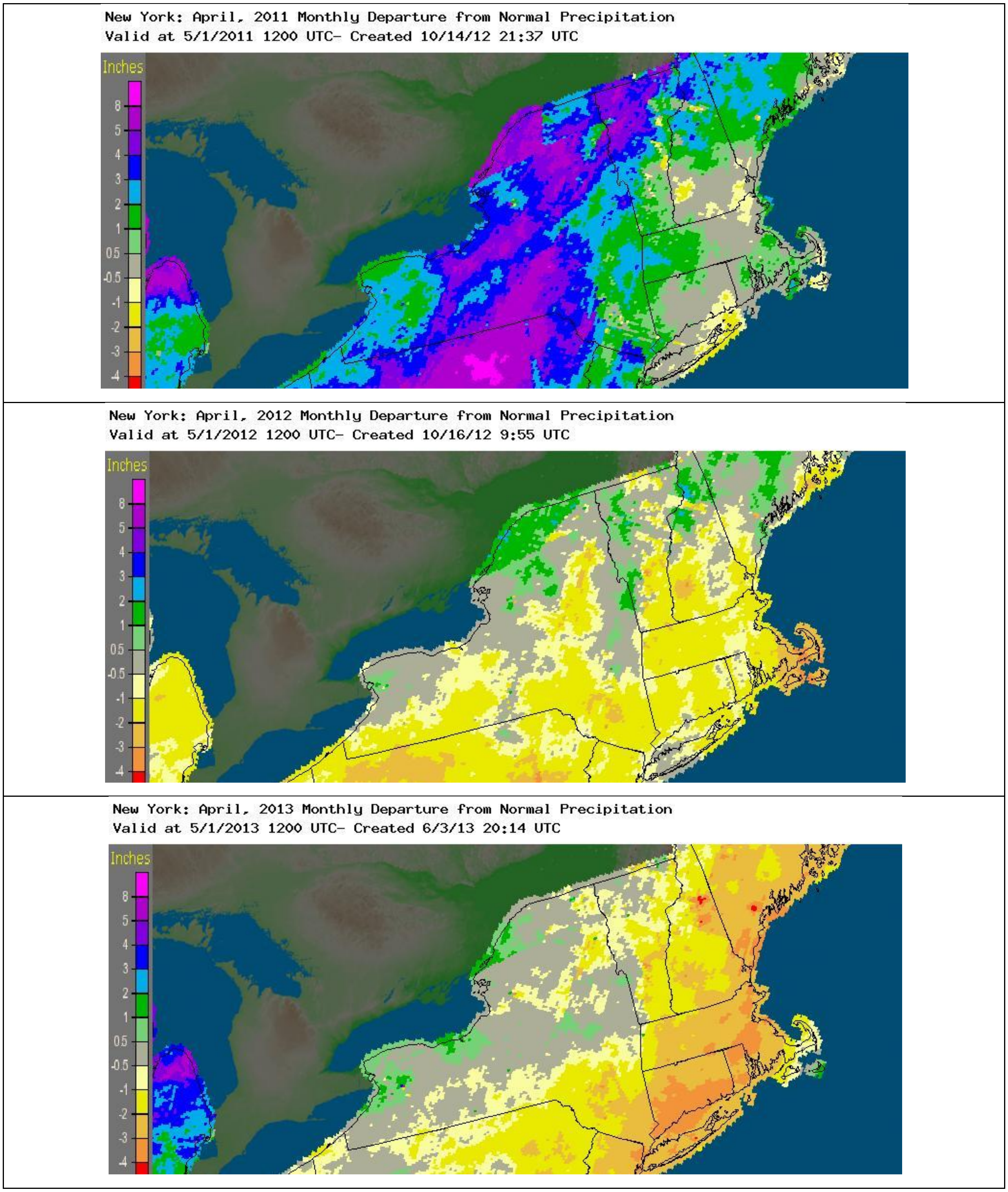


Figure 16b. Departure from average April precipitation for New York State. National Weather Service **http://water.weather.gov/precip/**

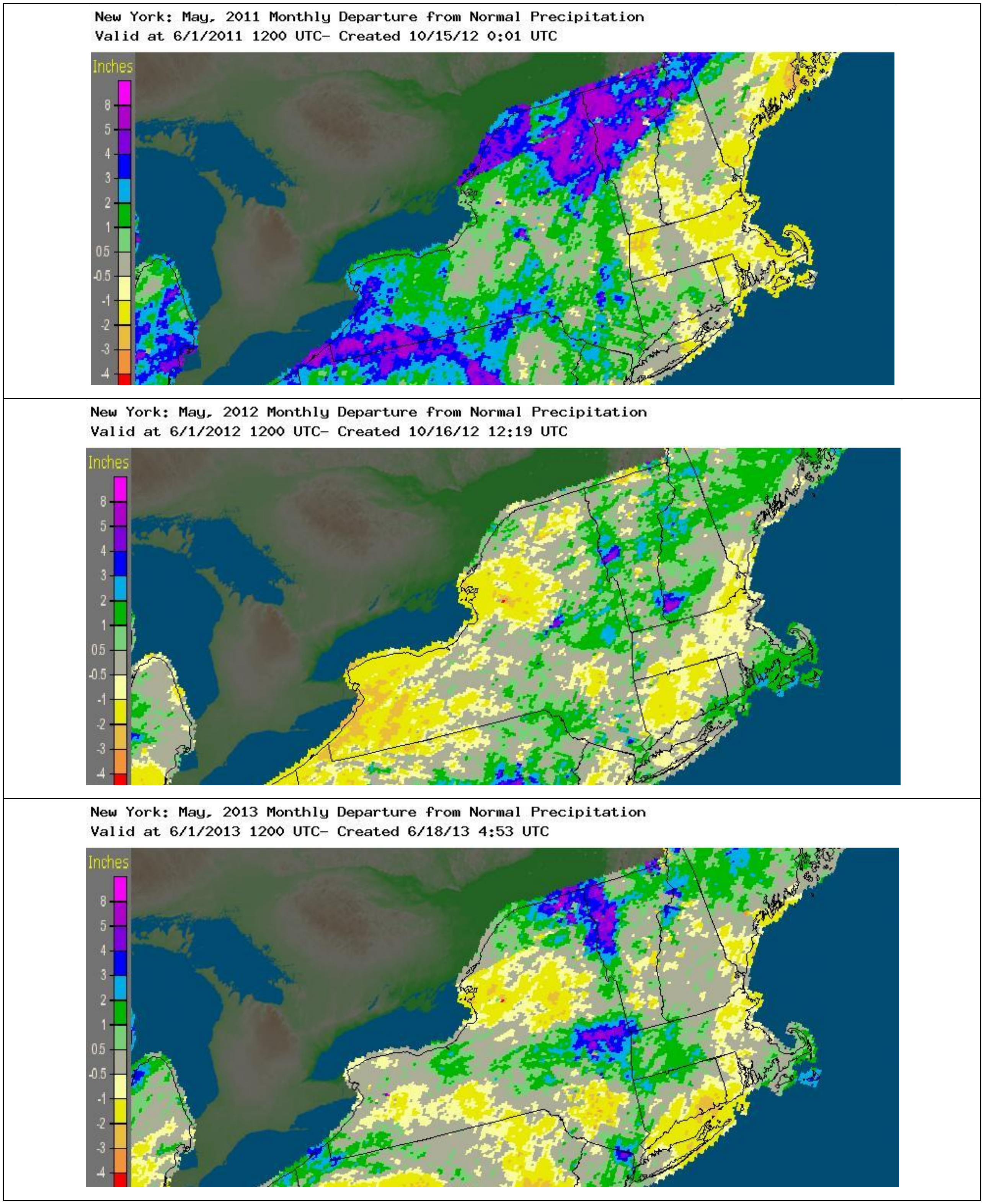


Figure 16c. Departure from average May precipitation for New York State. National Weather Service **http://water.weather.gov/precip/**

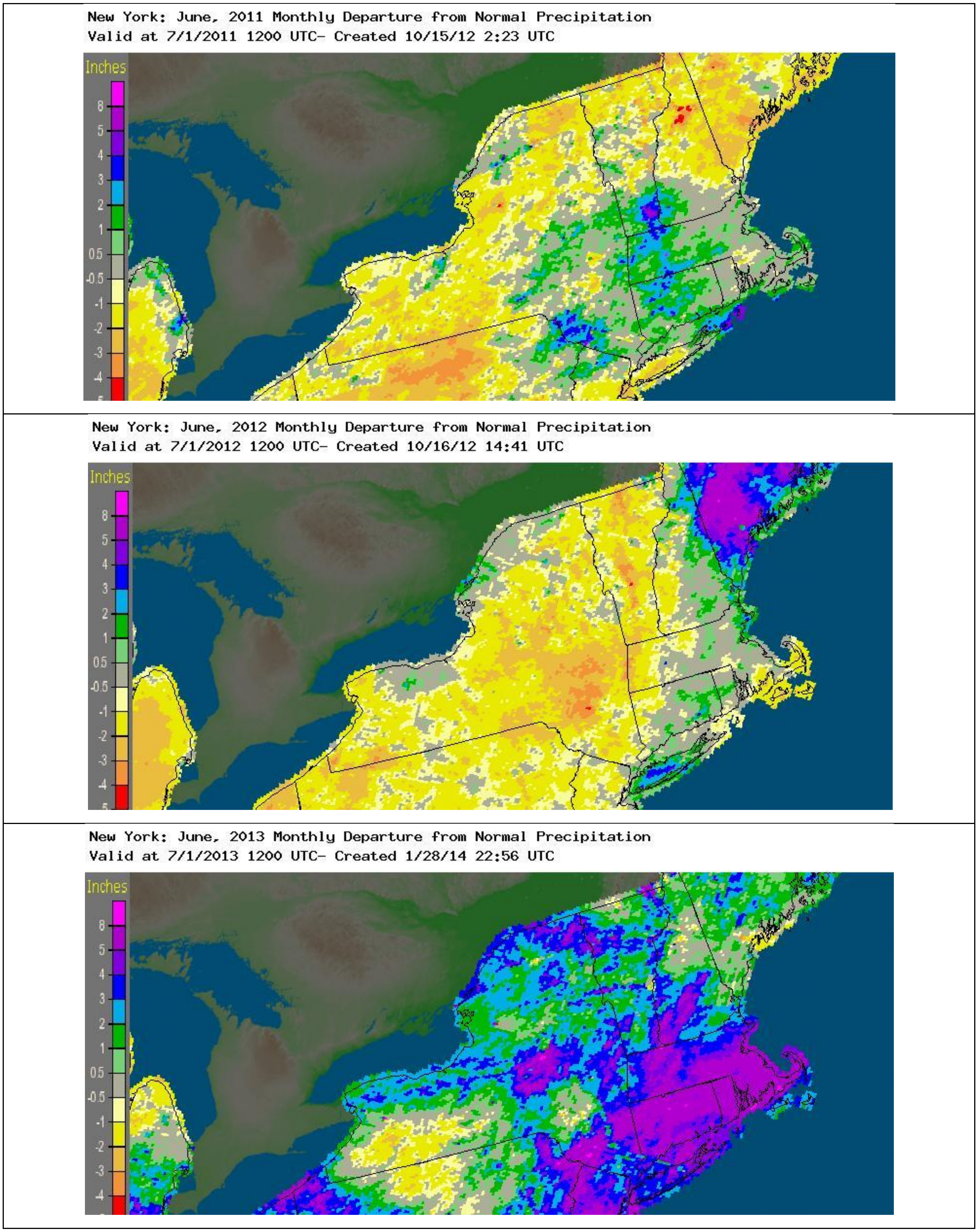


Figure 16d. Departure from average June precipitation for New York State. National Weather Service **http://water.weather.gov/precip/**

Interpretation

The apparent rapid loss of stocked trout from managed reaches could stem from multiple mechanisms including emigration out of the stocked reach, avian or mammalian predation, or natural mortality stemming from environmental factors. The causes of apparent mortality likely vary from stream to stream and in some cases a single factor may account for a substantial portion of the total loss. For example, in a recently completed study on the effects of Common Mergansers (*Mergus merganser*) on stocked yearling brown trout in the West Branch of the Delaware River above Cannonsville Reservoir, it was estimated that 51% of the stocked trout were consumed by this piscivorous species (Stiller, M.S. Thesis 2011). While an investigation into the causes of mortality for each stream managed by the NYSDEC would be extremely expensive and logistically difficult, an adaptive approach to stocking might yield insights into the causes of stocked trout mortality as well as methods to reduce stock loss. Capture probabilities were high for all streams across years, indicating that the standardized electrofishing sampling protocol was effective.

Wild Fish

In our examinations of the electrofishing population estimates, we found consistent differences in the pattern of change between spring and fall surveys (Figure 17-18). In the vast majority of surveys stocked trout declined between spring and fall as would be expected in a put-and-take fishery. Wild brown trout numbers, on the other hand, increased over the course of summer in most surveys. The pattern held even when non-catchable fish (those under 175mm) were excluded from consideration, indicating that a summer influx of young-of-the-year (YOY) trout from protected tributaries was not the cause. Potential explanations for this phenomenon include a competition effect from stocked trout that temporarily displaces wild fish from stocked sections or a behavioral difference in seasonal habitat preference between strains (Bachman 1984). No increase was seen even when fish <175mm were excluded from only the fall analysis, strongly suggesting that local recruitment into the catchable size range does not entirely explain the increase.

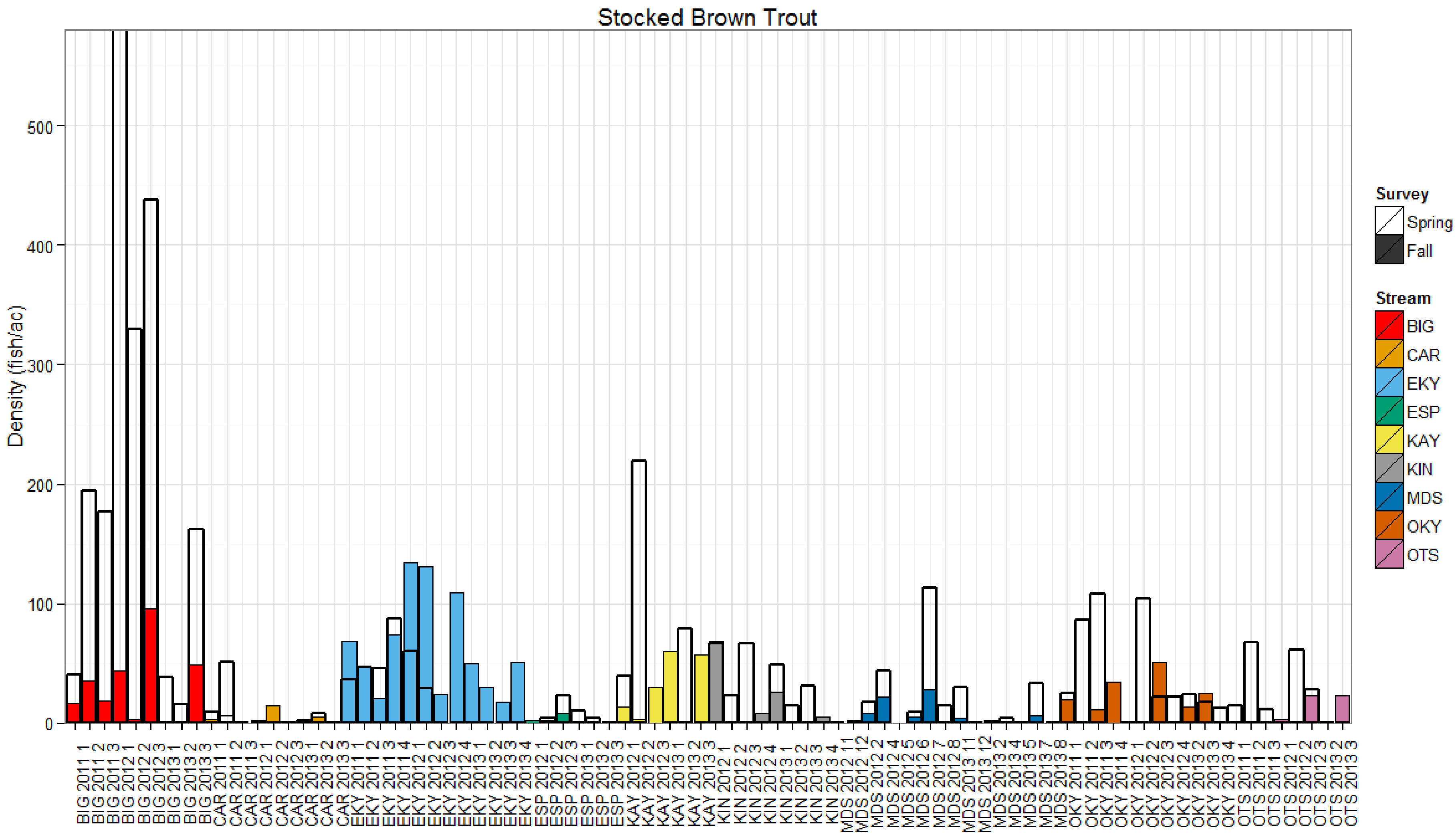


Figure 17. Comparison between spring and fall population density of stocked brown trout. Each bar denotes a single sampling site and year. Spring densities are shown as an unfilled bar and fall densities as a filled one. Therefore, bars with an unfilled top portion show sites where the density of fish decreased over the summer, while bars with a filled top represent the opposite.

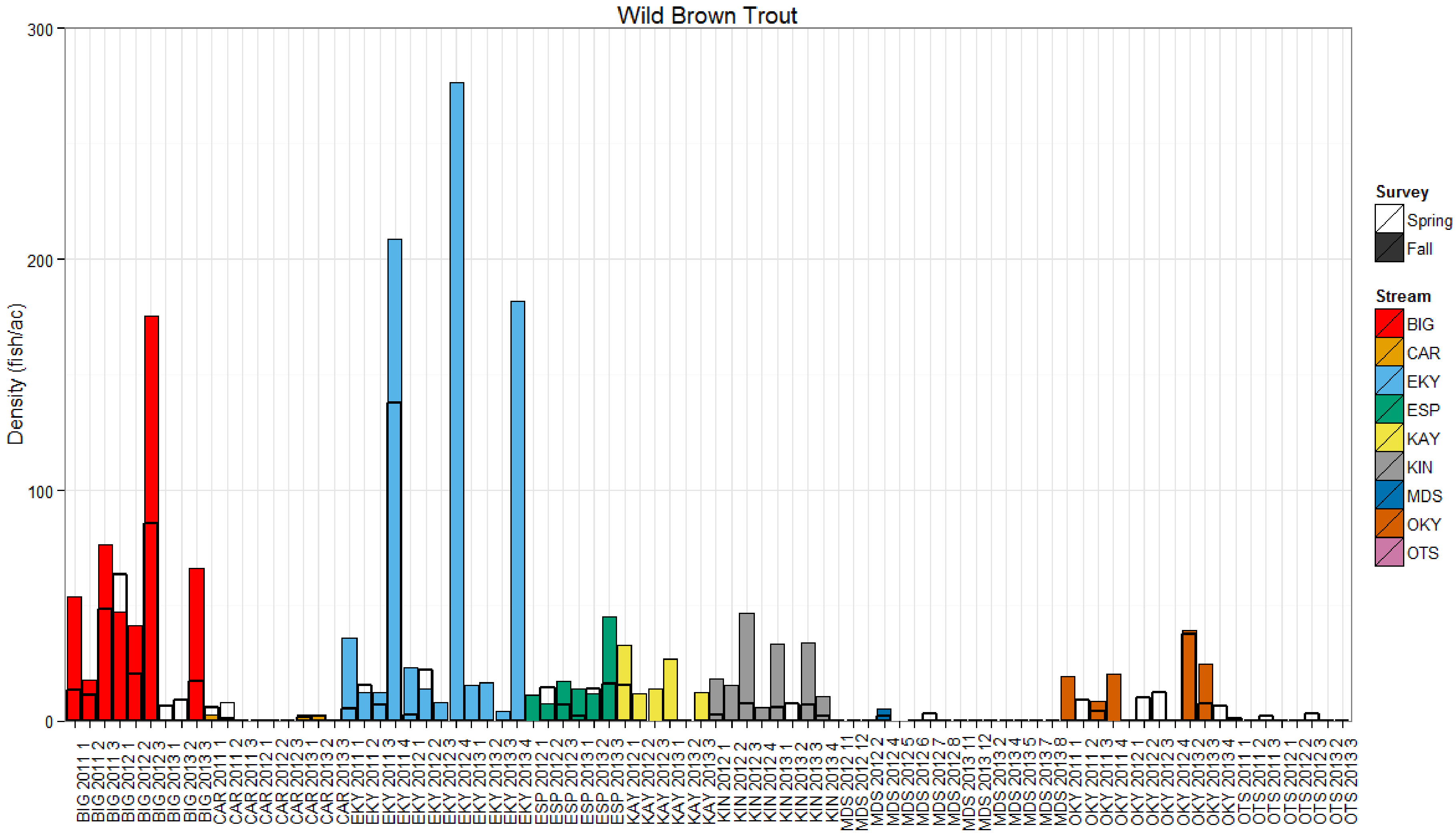


Figure 18. Comparison between spring and fall population density of wild brown trout. Each bar denotes a single sampling site and year. Spring densities are shown as an unfilled bar and fall densities as a filled one. Therefore, bars with an unfilled top portion show sites where the density of fish decreased over the summer, while bars with a filled top represent the opposite.

CROTS Population Dynamics Model

Structure

Model Development

The CROTS model is based on a standard population dynamics model. For any time period the number of fish present in a cohort is the number of fish present in the previous time period minus the exponential function of the total mortality during that time period (Ricker 1975). This can be expressed as:

$$N_t = N_{t-1} - e^{-Zt}$$

Total mortality *(Zt)* includes natural mortality*(zn)*, harvested catch *(Zc)*, and the portion of catch-and-release fish that die due to handling *(Zh)*. It should be noted that for purposes of convenience natural mortality accounts for all forms of non-fishing loss including predation, disease, environmental stress, and emigration.

$$Zt = zn + Zc + Zh$$

Harvested catch is a function of angler effort *(E_t)* multiplied by the catchability *(q)*. Catchability can vary due to a number of factors including gear, temperature, and date (Francis et al. 2001). Examination of our data suggested that catchability in the study streams was not related to any of these factors. Therefore catchability was estimated as a single coefficient for the season. As anglers do not harvest all fish, the portion kept or creel rate *(Pk)* must also be taken into account. In streams with size regulations or catch limits this rate may instead take the form of a probability function. The majority of study streams, however, had liberal take regulations relative to the observed creel rates such that their effect was negligible.

$$Zc = E_t * q * Pk$$

Total annual angler effort for a particular stream is estimated using instantaneous counts and a roving-roving creel survey (Pollock et al. 1994). However, distribution of effort is not always uniform across the fishing season. Potential effort distribution patterns other than uniform include those with the majority of the effort occurring at one end of the season. This can occur in the spring, such as in streams with spring stocking, or during the fall for those fisheries with fall spawning runs. To account for this, total effort *(E)* is multiplied by the portion of effort that occurs within that period *(Pt)* and divided by the total number of time units within that period.

$$E_t = \frac{E * P_t}{Tp_t}$$

Fish that are caught and released experience stress and injuries that may affect their ability to survive. The release mortality rate is dependent on the catch rate, the portion of fish not creeled, and the handling survival rate *(S)*.Survival rates of hooked fish appear to depend on multiple factors, including whether live bait or artificial lures were used (Taylor and White, 1992). As the percentage of anglers using bait was comparable across study streams this parameter was assumed to be constant. Some studies have suggested that size may affect hooking mortality, a concern in a model that addresses both yearling and two-year-old fish. However a meta-analysis of 53 studies found no significant relationship (Bartholomew and Bohnsack 2005).

$$Zr = E_t * q * (1 - Pk) * (1 - S)$$

Unlike in a wild fishery, the quantity of fish entering a put-and-take fishery is known, as is the time. When multiple stockings are done throughout the season this has the effect of dividing the population into cohorts. This is especially true if the fish in each stocking increment are marked for identification during population surveys. Modeling these cohorts separately allows for the analysis of effects such as stocking time and post-stocking loss. Additionally, if stocking increments differ in terms of age this allows for different mortality increments to be applied to each group. At any one time the total abundance can be represented as.

$$\sum_{i}^{c} N0_i e^{-Zt_i}$$

Where *c* is the total number of stocked cohorts and *N0* is initial number stocked for each cohort. Multiplying this expression of overall abundance by the catchability parameter provides the estimated angler catch-rate for the given time period.

Biomass and average length of stocked fish are also included in the CROTS model. Fish are stocked at a known length and the average length of wild populations can be obtained through electrofishing surveys. The average length at time *t* can therefore be expressed as the length at *t-1* multiplied by the exponential function of the growth rate. A standard fisheries length-weight relationship is used to convert mean length to mean weight (Schneider 2000).

$$L_{in} = \frac{(W_{lbs} * 45454545)^{1/3}}{25.4}$$

This is combined with the predicted population numbers to obtain an estimate of biomass for each cohort which can be summed to obtain an estimate of the total trout biomass at time *t*.

$$B_t = \sum_{c=1}^{sc} (N_{c,t}\, W_{c,t})$$

Parameters

The model is a function of seven parameters that can operate on various levels. In the original incarnation, most of the parameters were fixed at a global level. A key part of reassessing the model is examining the past parameter values and levels, evaluating the assumptions that lead to those values, and exploring options for future model designs.

Effort (E) and Pattern (P)

Effort in annual angler hours per acre is used to determine the fishing pressure on a given stream. This parameter is further modified by dividing streams up into one of two effort distribution patterns (Table 5). Pattern 1 streams have relatively steady effort throughout the fishing season with a gradual reduction towards the end of the season. Pattern 2 streams, on the other hand, see the majority of their effort immediately after stocking and have very little effort in the late season. Both effort and pattern are estimated from data gathered during season-long creel surveys over three years. These parameters vary on a stream level but are likely to be relatively consistent from year-to-year barring major changes in the fishery.

Table 5. Patterns of seasonal effort distribution.

	Apr	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
Pattern 1	0.27	0.25	0.19	0.14	0.06	0.07	0.02	0.01
Pattern 2	0.71	0.19	0.06	0.03	0.01	0.00	0.00	0.00

Creel Rate (pk)

As discussed previously, surveys showed that creel rates were significantly lower than the historical rate of 1.0 .This has the effect of de-emphasizing the importance of angler effort in the model, making natural mortality comparatively more important. Creel rate varies by stream with some streams in our study having a *p* of zero while others have rates as high as .4.

Handling Mortality (S)

Fish that are caught and released experience injuries and stress that may lead to mortality. A meta-analysis of handling mortality found rates for Brown Trout ranging from 0-28% depending on the conditions and type of lure used (Muoneke and Childress 1994). Differences in hooking mortality rates between wild and hatchery fish have also been observed (Taylor and White 1992). In a primarily catch-and-release fishery this parameter is an important driver of overall mortality, second only to natural mortality. The past models set the handling mortality at 10%, a fairly conservative estimate for the conditions. There is no reason to believe that handling mortality has changed significantly from previous models and it has therefore been left at its original value.

Catchability (q)

Catchability refers to the probability that a given fish will be caught within a unit of effort. Applied to population abundances it can be used to estimate CPUE while when applied to effort it provides an estimate of catch rate. As the rate depends on a number of variables including food supply, cover, and temperature no applicable information exists from previous studies. Evidence also exists for catchability decreasing as a function of fishing pressure, with hooked trout being reluctant to leave cover the following day (Young and Hayes 2004). As such, catchability for past CROTS models was estimated from observed CPUE and abundance data with the original value set to .00145 for yearling fish (Engstrom-Heg 1986).

Natural Mortality (zn)

Natural mortality or natural loss encompasses all sources of loss in fish that are not directly related to angling activities. This includes predation, disease, and emigration. As such, the rate can be variable and difficult to estimate as Engstrom-Heg acknowledges in the original model (Engstrom-Heg and Engstrom-Heg, 1984). Based on previous observations they concluded that .002 was a reasonable daily mortality rate for stocked brown trout, with the rate for wild trout likely being lower. Since that time there have been numerous changes to habitats and predator populations which have a bearing on natural mortality. We chose to re-estimate natural mortality using maximum likelihood estimation, a powerful technique not available when the original model was created.

Stocking Number (N_{t0})

The DEC stocks set numbers of trout at multiple locations along the sample streams. Trout release locations are spread out to encourage even dispersal and maximize habitat usage. Stocking numbers are estimated at the hatchery by volume and confirmed in the field by estimating the average number of fish per dip net and counting the total number of nets emptied into the stream. The model assumes that reported stocking numbers are accurate and that the distribution of fish at the time of stocking is uniform throughout the fished area of the stream.

Parameter Estimation

Estimation was accomplished by coding the model in the AD Model Builder (ADMB) environment. Parameter values were fit using a maximum likelihood estimation approach. In the case of ADMB this actually involves the minimization of the negative log-likelihood which is functionally equivalent, but easier to implement computationally (Fournier et al. 2012). Model predictions are fit to observed values for cohort population density and angler catch-rate using a weighted residual sum of square structure:

$$RSS = RSS_{density} + \lambda RSS_{cpue}$$

With the residual sum of squares for the density component taking the form of:

$$RSS_{density} = \sum_{c,t} (\widehat{D}_{c,t} - D_{c,t})^2$$

Where $\widehat{D}_{c,t}$ is the predicted density of a cohort and $D_{c,t}$ is the observed density of that cohort at time t. The residual sum of squares for the catch-rate is similar:

$$RSS_{cpue} = \sum_{t} (\hat{C}_t - C_t)^2$$

but is not divided by cohort as anglers do not reliably observe whether fish are marked. The weighting term λ in the combined RSS accounts for differences in magnitude and sample size between population density surveys and angler interviews. Values for λ were chosen so that both residual sum of squares elements were of the same magnitude, ensuring that the model tried to fit both sources of observations relatively equally. This weighted residual sum of squares is then used to calculate the concentrated form of the negative log-likelihood:

$$-logLikelihood = \frac{n}{2} \ln \frac{RSS}{n}$$

Where *n* is the total number of observations in both fitted datasets.

Model Selection

From a fisheries management perspective, the most useful model is the one that yields the best predictions of trout cohort densities and angler catch rates (compared to observed values at time t) while minimizing the number of parameters required. To that end, model scenarios were evaluated by comparing their Akaike Information Criterion (AIC) value. AIC balances goodness-of-fit, quantified as described in the preceding section, with penalties for model complexity, thereby discouraging over-parameterization. First introduced in 1974 AIC has become a widely accepted method of model selection due to its ease of use and basis in information theory (Johnson and Omland 2004). Models with lower AIC values are preferred and a difference larger than two is considered to be significant. If two models have the same AIC or an insignificant difference between them the most parsimonious model is generally considered superior.

Twelve separate candidate models were developed by subdividing the natural mortality into multiple levels based on spatial, temporal, and biological characteristics thought to have a possible influence on mortality. Catchability was estimated as a global constant in all models, due to the limited data available from fishermen about marks, size, and age of caught fish. Models were then run using the same base data and initial parameter estimates and differing only in parameterization (Table 6).

Table 6. Candidate models ranked by performance (efficacy in predicting trout population density and angler catch rate vs. model complexity).

Model #	Model	K	AIC	ΔAIC	Akaike weight
6	q, Zn(Stream)	10	7133.00	0.00	0.93
2	q, Zn(Stream Type (A/B))	3	7138.62	5.62	0.06
4	q, Zn(Age + Stream Type)	5	7142.44	9.44	0.01
10	q, Zn(Age + Stream)	16	7143.70	10.70	0.00
9	q, Zn(Stream + Year)	24	7144.60	11.60	0.00
5	q, Zn(Year)	4	7184.96	51.96	0.00
1	q, Zn	2	7189.00	56.00	0.00
8	q, Zn(Age + Year)	7	7190.90	57.90	0.00
7	q, Zn(Effort Pattern)	3	7190.96	57.96	0.00
3	q, Zn(Age)	3	7190.98	57.98	0.00
11	q, Zn(Age+Stream+Year)	39	7201.80	68.80	0.00
12	q, Zn(Stream Type + Effort Pattern)	4	7396.20	263.20	0.00

CROTS Workbook

The first two versions of the CROTS population dynamics model were programmed in FORTRAN by Engstrom-Heg and known as STREAM/SOURCE. Later this was translated to a LOTUS worksheet under the name Trout 4x4. This was used by the NYSDEC as the primary stocking assessment for many years. More recently an interactive Microsoft Visual Basic version called Trout.exe was created by Cornell Graduate Student Theodore Treska. While planning the updated model, DEC biologists stated that they were more comfortable with a spreadsheet-based model compared to a more opaque method such as Visual Basic. The decision was made to create the updated CROTS model in Microsoft Excel due to biologist familiarity, ease of modification, and the likelihood of future software support.

The primary objectives of the CROTS workbook are to:

1. Provide a simple, easy-to-use method for planning Catch Rate Oriented Stocking.
2. Enable biologists to evaluate new stocking scenarios and adapt to changing conditions
3. Allow for modification to fit changing human and environmental fisheries variables.

To fulfill these objectives, a multi-sheet Excel Workbook known as Trout2014 has been created. The workbook has several levels that are intended to allow for quick evaluation of basic scenarios while still allowing for finer, more detailed control when necessary. Instructions for using the Trout2014 worksheet can be found in Appendix E.

SY vs. 2Y trout

In the 1980's and 90's when the CROTS model was first implemented, the NYSDEC was only stocking spring yearling (SY) trout in the 9 inch or 22 centimeter range. Currently, many streams across New York State receive stocked 2 year old trout (2Y), however, the CROTS model has not been updated to include the changes in trout population dynamics and angling patterns associated with the inclusion of 2Y.While Treska (2005) found no significant difference in mean abundance of SY in the presence or absence of 2Y, knowledge and insight into the population and angling dynamics of the 2Y themselves could be of great importance to the CROTS model and the NYSDEC trout stocking program. To this end, we investigated the harvest and mortality of 2Y and compared the parameters to those of SY in addition to including 2Y stocking in the CROTS model.

2Y Catch and harvest

The regional biologists and managers hypothesized that 2Y trout are caught and harvested at higher rates than one year olds. Due to the high release rates of all caught trout in this study, we were unable to examine catch differences between 2Y and SY because we relied on angler reporting for released trout and angler reports on clip type and size were unreliable. Thus, we were only able to examine differences between 2Y and SY on the subset of trout that were harvested by anglers and examined by the creel agent. Inference was limited to differences in proportional harvest between the two groups. Absolute differences in harvest between the two groups would be misleading since ten times as many SY are stocked as 2Y. To correct for this difference, we standardized the population according to number stocked and calculated the mean proportion of stocked 2Y and SY harvested daily. This statistic illustrates the relative difference in harvest rates between the two groups based on the number of fish available.

Though we were unable to separate 2Y and SY fish that were released, we were able to analyze differences between catch and harvest rates between small (>12 in.) and big (<12 in.) fish using fish lengths measured by the creel agent and angler reported fish lengths. This dichotomy allowed us to include creeled and released fish in our analysis. Combining data from all nine streams for the entire three year period, we had a total of 184 angler days for when big fish were caught and 294 angler days for when small fish were caught. We calculated a daily catch (CPUE) and harvest (HPUE) rate (fish/hour). We log transformed non-normal data and tested for homogeneity of variance using a Levene's test. When variances were non-homogenous, we used a Mann-Whitney U test.

We estimated a mean daily proportional harvest rate of 0.00019 for 2Y and 0.00002 for SY (Figure 19). A Mann-Whitney rank sum test showed that the difference was highly significant ($P < 0.001$). This finding supports the hypothesis that 2Y are harvested at a higher proportion of their stocking number than SY. It is important to keep this statistic in perspective in terms of the absolute numbers of fish stocked. Our findings indicate that daily harvest for both groups represents a very small proportion of the population; orders of magnitude lower than estimated daily natural mortality. Consequently, while there appears to be a significant difference in proportional harvest between the two age classes, harvest does not have major implications for their population dynamics. Big fish and small fish appeared to be caught at similar rates (Mann-Whitney U test; p=0.203) (Figure 20). Harvest rates between big and small fish were significantly different with big fish being harvested at a rate of approximately 0.32 fish per hour compared to a harvest rate of 0.11 fish per hour for small fish (Figure 20).

Mortality

Estimated apparent natural mortality rates for SY and 2Y fish were not significantly different (Figure 21). This could be due in part to the variation caused by the much smaller numbers of 2Y fish stocked relative to SY. Estimated rates across all streams, however, were very similar with values of .0233 and .0198 for SY and 2Y brown trout, respectively. This lack of influence can also be seen in the model comparison analysis where none of the top models included age as a factor (Table 5).

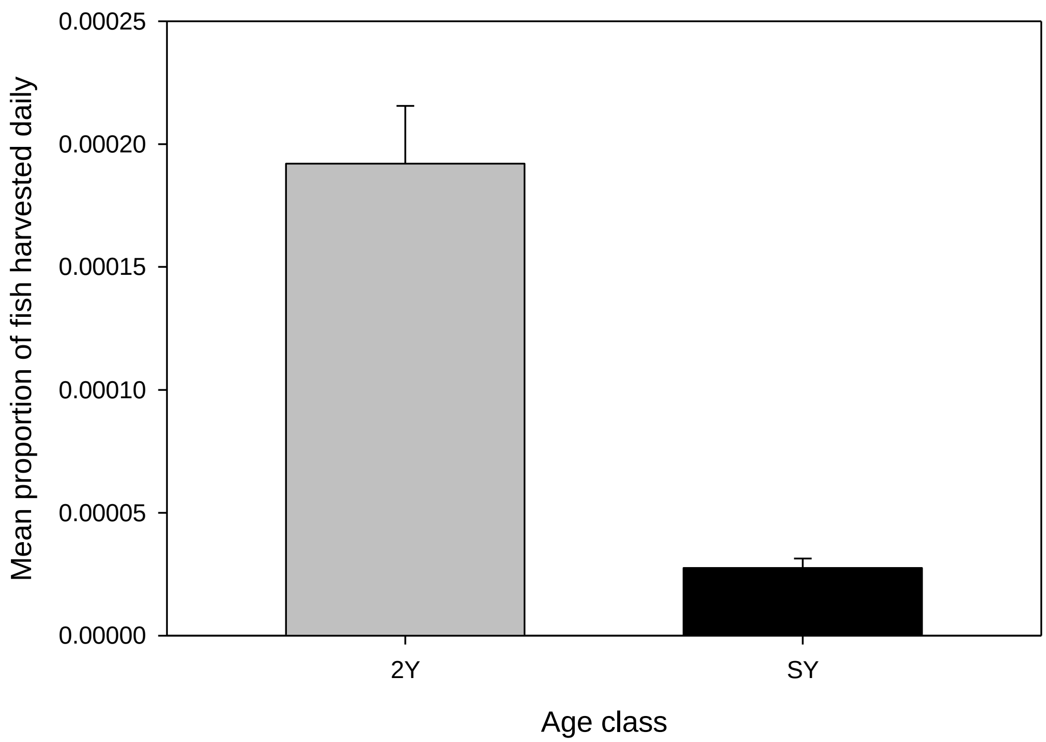


Figure 19. Mean proportion of 2Y and SY stocked brown trout harvested. (Note that these estimates are limited to the subset of fish that were harvested by anglers and examined by the creel agent, and thus may not be indicative of overall catch patterns).

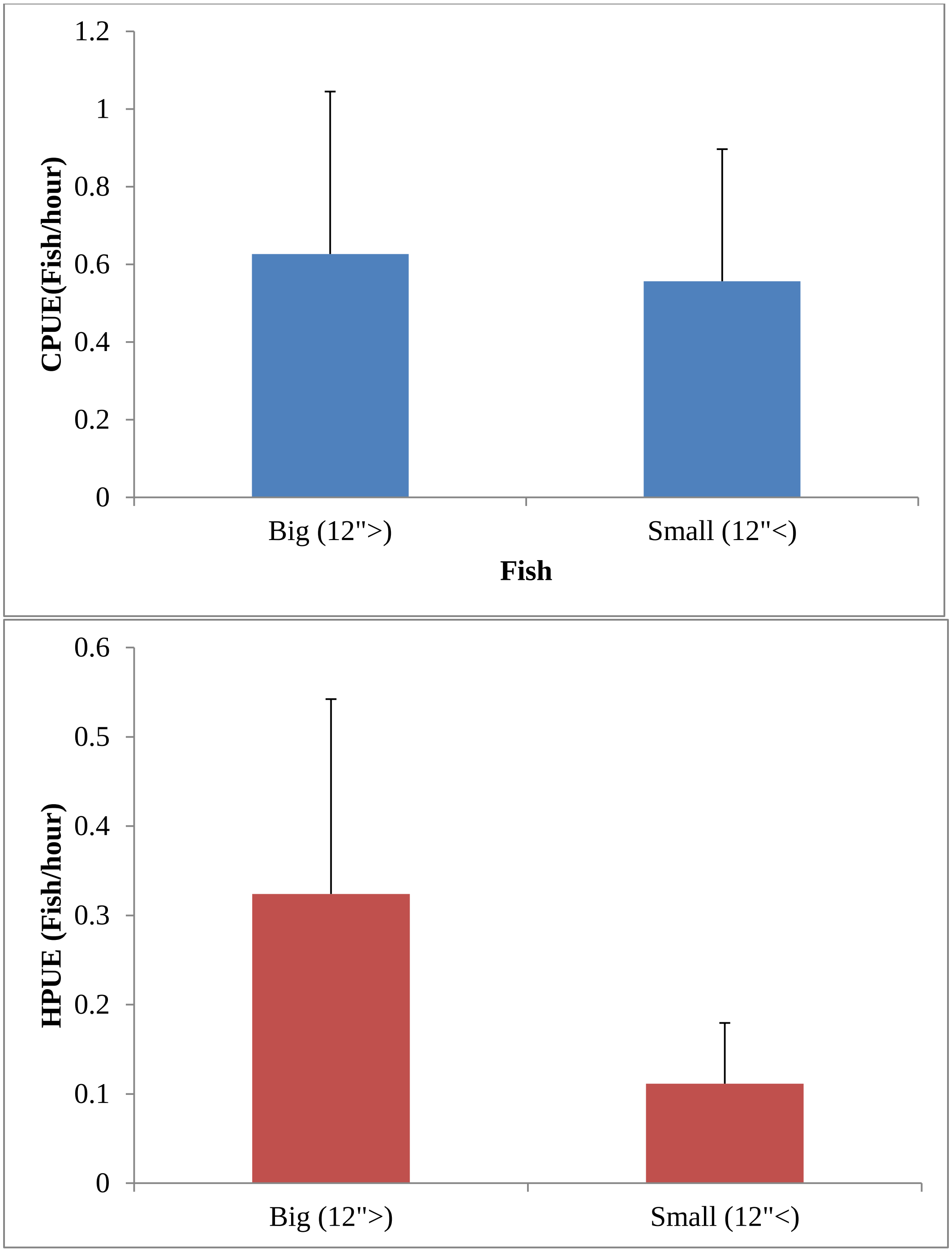


Figure 20. Estimated mean CPUE and HPUE (harvest per unit effort) +/- one standard deviation for big fish (larger than 12 in) and small fish (smaller than 12 in.). Estimates were calculated with a total of 294 angler days for small fish and 184 angler days for big fish.

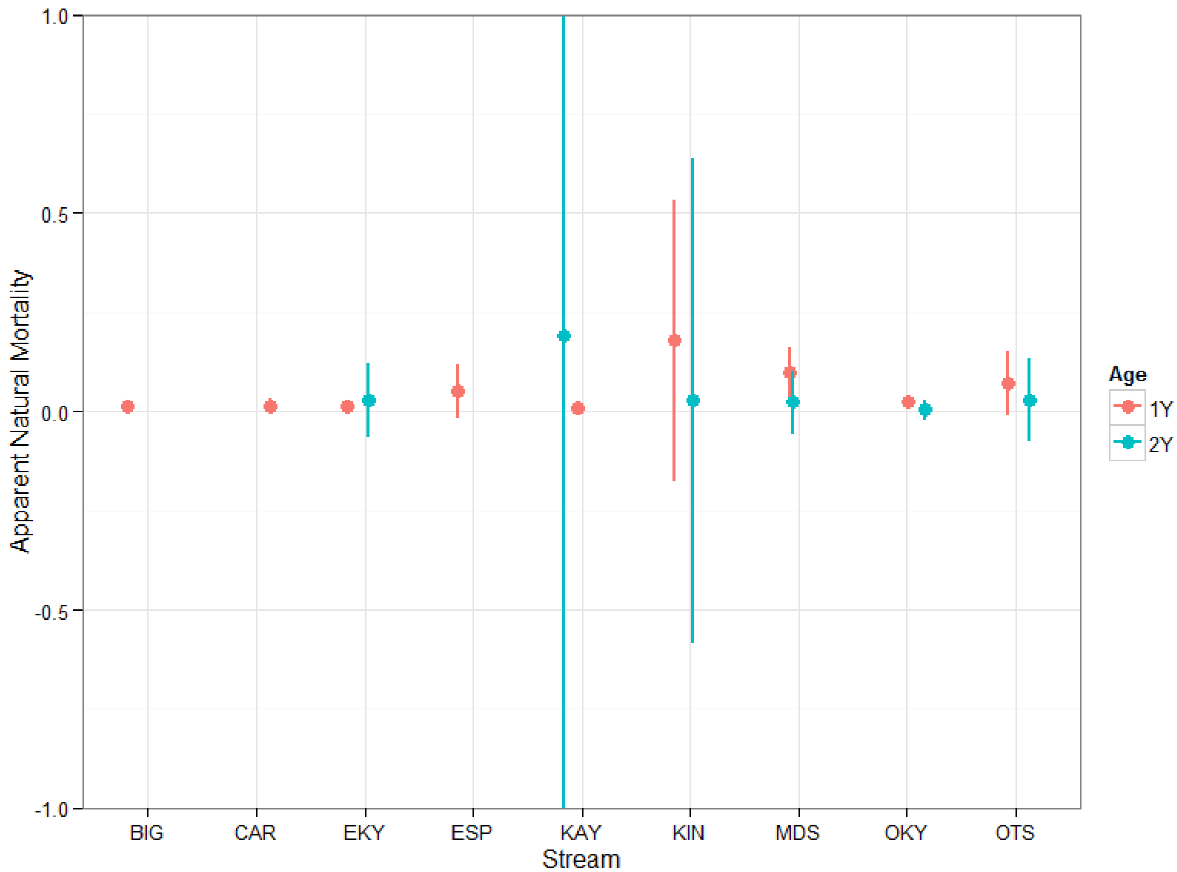


Figure 21. Estimated apparent natural mortality rates for one and two year old fish by stream.

Conclusion

The results of this study demonstrated that some model parameters have changed significantly since previous CROTS surveys. Estimated values of daily instantaneous rates of apparent natural mortality were .0147 and .088 for A and B streams, respectively. These are roughly an order of magnitude higher than the CROTS assumed daily instantaneous mortality rates of 0.002 for A streams and 0.005 for B streams.

Due to this accelerated loss rate, the number of trout surviving from stocking year *t* to year *t +1* (hereafter “holdovers”) was negligible during the study (Table 7). Holdover trout from the previous year are assumed to make up a portion of the fishery under the current CROTS system for “A” streams, an assumption that was not met during this study.

Table 7. Total number of holdover trout (determined by fin-clip type) captured during electrofishing sampling in 2012 and 2013.

Stream	Year	
	2012	2013
Big	0	0
Carmans	0	2
East Koy	1	4
Esopus	0	0
Kayaderosseras	0	1
Kinderhook	0	0
Meads	0	0
Oriskany	0	0
Otselic	0	0

Angler effort also appears to be much lower than estimates from creel surveys conducted during the 1980’s and 1990’s. Proportion of fish creeled (Pk) was also significantly lower than the CROTS assumed rate of 1.0. These parameter changes represent a fishery that differs markedly from the one modeled in the original CROTS. Mean seasonal CPUE estimates for the study appeared to be very close to the target rate of 0.5 when estimated from incomplete trips alone, though estimates may have been affected by measurement error (see Appendix C). Furthermore, given the high natural mortality rates for stocked trout in the study, and the apparent increase in wild trout over the course of the fishing season, it is likely that wild trout are making up a large part of the fishery. Unfortunately, due to the high release rate of fish in the study, it was difficult to test this assumption directly in the creel surveys; however, the low harvest rate of trout in these streams indicates that angler pressure on the wild trout fishery likely does not have a major influence on the population. The parameter estimates from the study will allow us to improve the model and likely lead to changes in stocking numbers for the streams in the study. If these streams are indeed assumed to be adequate representatives of streams in their respective regions, then these findings might necessitate eventual changes for the entire NYSDEC trout stocking program. Given the high level of social, economic, and cultural importance of trout fishing in New York State, and the inherent uncertainty associated with any empirical study, it is important to take an experimental or “adaptive management” based approach to addressing these changes. Adaptive management is widely considered the best approach to dealing with uncertainty in natural resource decision making (Walters 2007). The basis of adaptive management holds that policy choices should be treated as deliberate, large scale experiments.

Recommendations

Sullivan and Kraft (2005) assessed the CROTS program and recommended an “action-evaluation” management strategy to improve fisheries management practices in New York streams. Within the “action-evaluation” framework, a stream is evaluated (i.e., angler effort, fish abundance) and compared to the original (historic) assessment. Based on the evaluation, an action is taken (e.g., regulation change, stocking level adjustment), the stream is re-evaluated, and the response is compared to the original assessment after which further action is taken (Krueger and Decker 1999). This methodology is similar to the adaptive management concept (Johnson 1999) which has been widely accepted and implemented in natural resources management. For this study, we evaluated parameters of the CROTS model. Our findings indicated major parameter deviations from values used in the original CROTS model and provide baseline estimates for comparison to future studies following management actions. Exploration using model selection confirmed that the current DEC method of dividing natural mortality rates by stream type, i.e. separate mortality rates for "A" and "B" streams, is efficient and fits the data relatively well.

The next step in the “action evaluation loop” would be to choose a representative subset of stocked streams on which to conduct experimental management actions (e.g., different stocking densities, creel limit or regulation changes) after which creel surveys and fish population estimates could be conducted to evaluate the consequences of the action. The subset of streams could include the streams involved in this study or any other managed streams with a recent creel census and trout abundance survey. For example, on a group of streams with similar habitat, angling pressure, and wild trout densities, managers might cease stocking altogether on one stream, increase stocking on another, and follow standard CROTS model recommendations on a third stream as a control. The next step in the active management framework would be to update management actions based on the findings of the evaluation. Based on the findings of an experiment such as our example above, stocking rates might be altered to produce an optimal catch level, or remain the same should the CROTS model stream yield the best outcome.

Long term, standardized monitoring is critical for providing key insights in environmental change, natural resource management, and ecology of stream systems (Lindenmayer et al. 2012). Perhaps the most important component of the action evaluation framework and among the most important recommendations we can offer would be to implement a standardized, long term sampling protocol on a set of streams with which to evaluate both annual and long term fluctuations in environmental, biological, and angling patterns. The temporal and regional variability in sampling survey methodology makes it difficult to compare our estimates to historical data. We believe that long term, standardized sampling could provide data to support evidence based policies and decisions for trout fisheries management.

Previously, the CROTS target of maintaining a 0.5 fish/hour catch-rate was evaluated as a simple mean for each month, with the goal of providing an average catch-rate greater than 0.5 for all months within the fishing season. While the shorter season of B streams was accounted for using this method, it did not consider the pattern of angler effort for each stream. Implementing a weighted catch-rate metric that takes into account the effort distribution of the stream allows for the maximization of catch-rate for the average angler, as opposed to maximizing effort for both early and late season anglers, the latter of which may be quite rare in some streams. For streams where effort is uniformly distributed throughout the season the two metrics will be very similar, however in those streams where the majority of effort occurs at the start of the season this can have profound effects on whether the stream is hitting the target catch-rate. As such, a weighted average should be considered when developing future CROTS goals. To help with the exploration of this metric, it has been included in the Trout2014 outputs.

The handling mortality rate for caught-and-released fish has become much more important due to high release rates, making it an important component of the CROTS model. Previous model values for handling mortality have been taken from existing literature but published rates vary widely. An experimental study of handling and hooking mortality in Rome-strain brown trout would yield more accurate values for the CROTS model and would be relatively simple and inexpensive to conduct.

We also recommend incorporating a creel census data table into the current statewide fisheries database (SWFDB) structure or creating a similar database for creel data alone. Through collaborations with regional managers and biologists, we found that there is a wealth of data available in paper or outdated software formats that are not readily available for analysis.

While there would be an initial time investment to format these data and enter them into the SWFDB, the data were collected at even greater expense and could provide invaluable insights into cold and warmwater fisheries, and thus should be made available for future analysis. Creation of a statewide creel database would also be an important component of the action-evaluation loop. If long term, standardized data on trout fisheries are to be collected, then a centralized data storage system would be the best way to ensure the data are accessible to bureau managers and used in the decision making process.

Catchability Study

While most CROTS parameters can be calculated or estimated from the observations made during this study, catchability of stocked trout in NY waters is largely unknown. A study designed to evaluate catchability of stocked and wild fish of various ages would greatly benefit our understanding of stocked fish behavior. As catch-rate is simply a function of population density and catchability, knowledge of this parameter is critical to effectively maintaining target catch-rates. Ideally such a study would be designed to assess changes in catchability throughout the fishing season so as to better understand its impact on catch rates.

Our study was not designed to assess catchability, but we can gain a rough idea about the catchability rates in the study streams by comparing the creel survey catch-rates to electrofishing population surveys that occurred within the same time period. Since catchability (q) is the rate at which each individual fish is caught, catch-rate or CPUE is that rate multiplied by the number of fish present:

$$CPUE = qN$$

By examining the relationship between CPUE and N we can get an idea of how q is behaving. To do this we subset those creel interviews that were within three days before or after an electrofishing survey (six days total). Creel interviews conducted on the day of an electrofishing survey were ignored due to the possibility that the survey would disrupt fishing. Interviews from the period prior to electrofishing were compared to those afterwards and no significant difference was found. The catch-rate for each interview longer than 30 minutes was then plotted against the average density of brown trout observed within that fishing area (Figure 14).

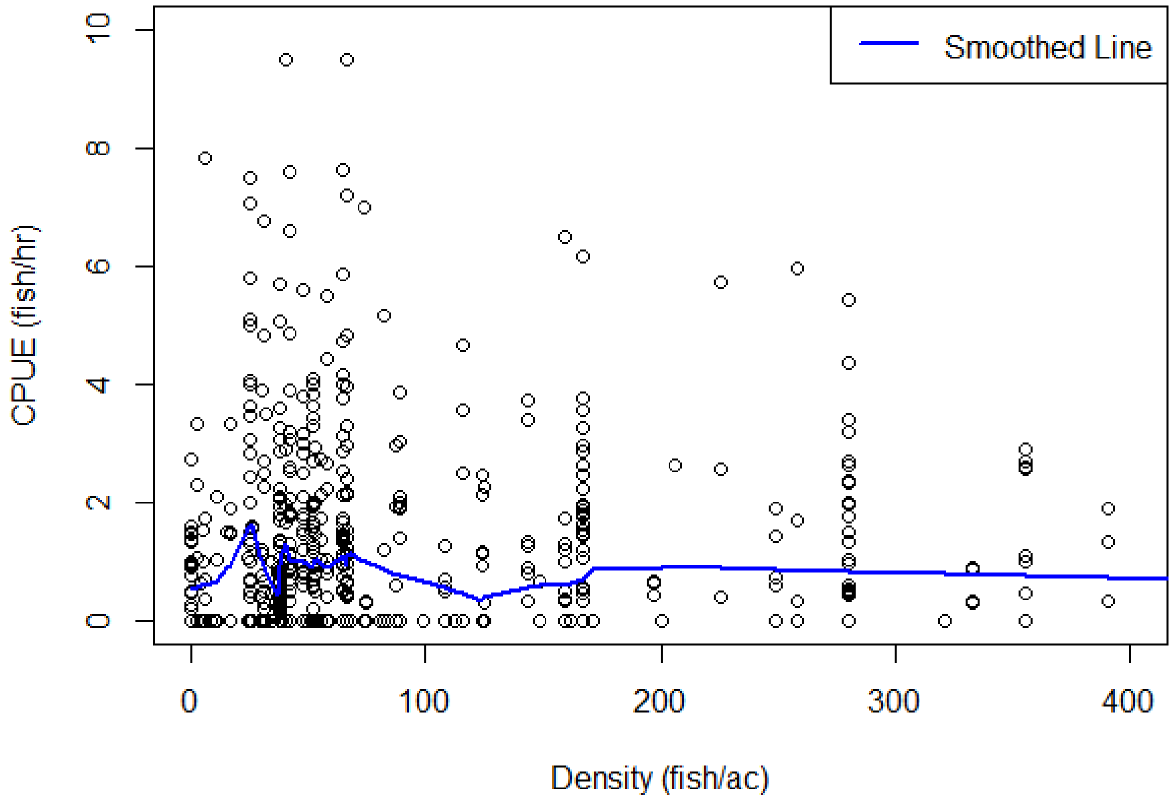


FIGURE 14: Observed catch-rate vs. electrofishing survey population density for all streams and years.

The results suggested that catch-rate and density were unrelated. This could be due to other factors influencing catchability such as temperature or cloud cover. Another explanation would be that beyond a certain point angler's gear is "saturated". That is, due to competition between fish and the fact that an angler can only capture one fish at a time, there is a population density beyond which catch-rate does not improve. It is also possible that, beyond a threshold level of angler effort, the most productive fish holding habitat in the stocked reach is saturated with anglers and additional anglers are obliged to fish less productive habitat thus effectively reducing the mean value of q. The suggestion that zero-catch anglers, those whose lack of success may be due to deficiencies in skill rather than availability of fish, might be biasing the trend downwards was explored by removing those anglers from consideration. This raised the mean catch rate but had no discernable effect on the relationship between catch-rate and density (Fig 15).

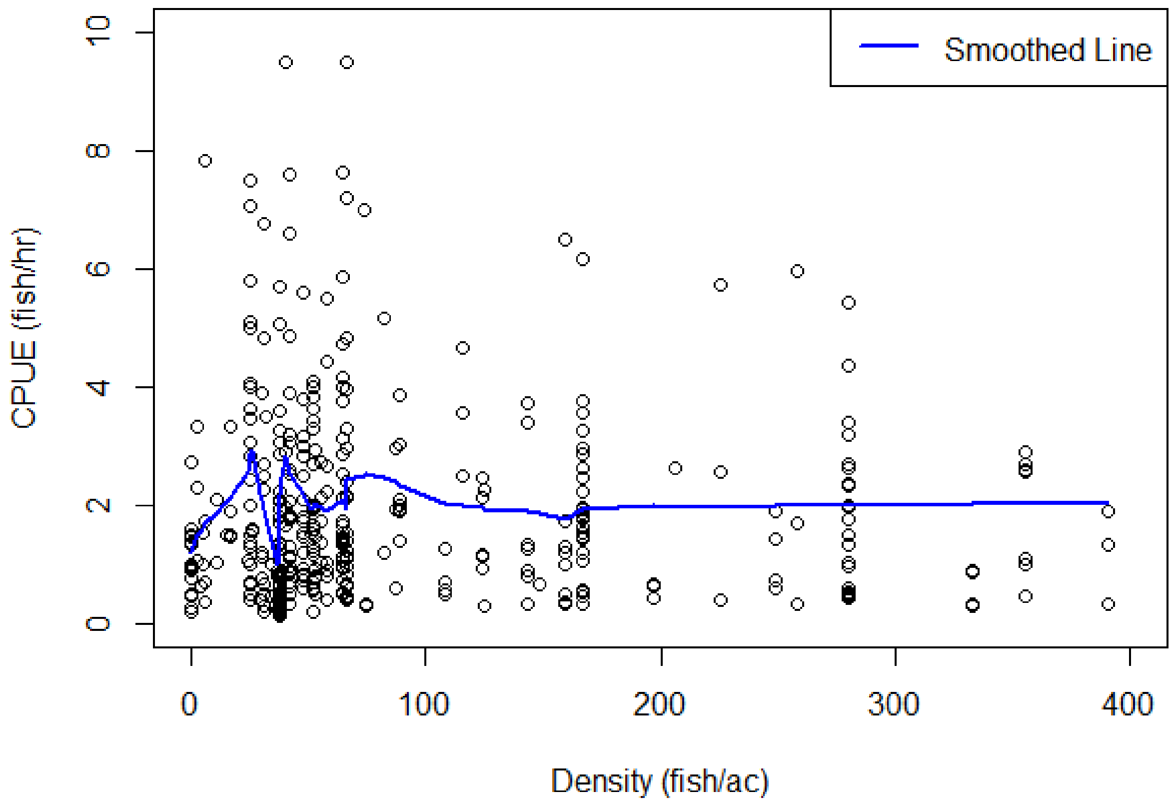


FIGURE 14: Observed catch-rate vs. electrofishing survey population density for all streams and years with zero-catch anglers removed.

References

Alexander, G. R., and Michigan.Fisheries Division. 1977. Consumption of small trout by large predatory brown trout in the north branch of the au sable river, Michigan. Michigan Dept. of Natural Resources, Fisheries Division.

Bachman, R. A. 1984. Foraging behavior of free-ranging wild and hatchery brown trout in a stream. Transactions of the American Fisheries Society 113(1):1-32.

Bartholomew, A., and J. A. Bohnsack. 2005. A Review of Catch-and-Release Angling Mortality with Implications for No-take Reserves. Reviews in Fish Biology and Fisheries 15(1-2):129–154.

Beverton, R., and S. Holt. 1957. On the dynamics of exploited fish populations. fisheries investigation series 2 (19). london: Ministry of agriculture. Fisheries and Food.

Binns, N. A., and F. M. Eiserman. 1979. Quantification of fluvial trout habitat. Transactions of the American Fisheries Society 108:215-228.

Brooks, J. E., M. J. Buntjer, and J. R. Smith. 2000. Non-native species interactions: Management implications to aid in recovery of the Colorado pikeminnow(P*tychocheiluslucius)* and razorback sucker*(Xyrauchen texanus*) in the San Juan river, CO-NM-UT.

Cambray, J. A. 2003. Impact on indigenous species biodiversity caused by the globalization of alien recreational freshwater fisheries. Hydrobiologia 500(1):217-230.

Connelly, N. A., and T. L. Brown. 2009. New York statewide angler survey 2007, report 2: Angler effort and expenditures. New York Statewide Angler Survey 2007, Report 2: Angler Effort and Expenditures .

Dewald, L., and M. A. Wilzbach. 1992. Interactions between native brook trout and hatchery brown trout: Effects on habitat use, feeding, and growth. Transactions of the American Fisheries Society 121(3):287-296.

Engstrom-Heg, R. 1986. Prediction of Wild Brown Trout Catch Rates from Estimated Yearling Population Density and Fishing Intensity. North American Journal of Fisheries Management 6(3):410–417.

Engstrom-Heg, V., and R. Engstrom-Heg. 1984. A FORTRAN Program for Predicting Yields of Stocked Trout from Stream Fisheries under Various Management Alternatives. North American Journal of Fisheries Management 4(4A):440–454.

Engstrom-Heg, R. 1990. Guidelines for stocking trout streams in New York state. New York State Department of Environmental Conservation 50.

Epifanio, J., and D. Nickum. 1997. Fishing for answers: Status and trends for coldwater fisheries management in Colorado. Trout Unlimited, Washington, D.C.

Fournier, D. A., H. J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M. N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optimization Methods and Software 27(2):233–249.

Francis, R., R. J. Hurst, and J. A. Renwick. 2001. An evaluation of catchability assumptions in New Zealand stock assessments. Ministry of Fisheries.

Gardner, B., P. J. Sullivan, and A. J. Lembo Jr. 2003.Predicting stream temperatures: Geostatistical model comparison using alternative distance metrics. Canadian Journal of Fisheries and Aquatic Sciences 60(3):344-351.

Hickley, P., and H. Tompkins. 1998. Recreational fisheries: Social, economic and management aspects. Fishing News Books, .

Hulbert, P. 1985. Post-stocking performance of hatchery-reared yearling brown trout. New York Fish and Game Journal 32(1):1-8.

Hoenig, J. M., C. M. Jones, K. H. Pollock, D. S. Robson, and D. L. Wade. 1997. Calculation of catch rate and total catch in roving surveys of anglers. Biometrics :306-317.

Johnson, B. L. 1999. The role of adaptive management as an operational approach for resource management agencies. Conservation Ecology 3(2):8.

Johnson, J. B., and K. S. Omland. 2004. Model selection in ecology and evolution. Trends in Ecology and Evolution 19(2):101–108.

Jones, C. M., D. S. Robson, H. D. Lakkis, and J. Kressel . 1995. Properties of catch rates used in analysis of angler surveys. Transactions of the American Fisheries Society. 124(6):911.

Kerr, S. J., and R. E. Grant. 2000. Ecological impacts of fish introductions: Evaluating the risk. Fish and Wildlife Branch, Ontario Ministry of Natural Resources.

Krueger, C. C., and D. J. Decker. 1999. The process of fisheries management. Inland Fisheries Management in North America, 2nd Edition.American Fisheries Society, Bethesda, Maryland 31-59.

Leary, R. F., F. W. Allendorf, and S. H. Forbes. 1993. Conservation genetics of bull trout in the Columbia and Klamath River drainages. Conservation Biology 7(4):856-865.

Lindenmayer, D. B., Likens, G. E., Andersen, A., Bowman, D., Bull, C. M., Burns, E., ... and Wardle, G. M. (2012). Value of long-term ecological studies. Austral Ecology, 37(7), 745-757.

Malvestuto, S. 1996. Sampling the recreational creel. Fisheries Techniques, 2nd Edition. American Fisheries Society, Bethesda, Maryland 591-623.

Muoneke, M. I., and W. M. Childress. 1994. Hooking mortality: A review for recreational fisheries. Reviews in Fisheries Science 2(2):123–156.

Pollock, K. H., Jones, C. M., and Brown, T. L. (1994).Angler survey methods and their applications in fisheries management.American Fisheries Society.

Pollock, K. H., J. M. Hoenig, C. M. Jones, D. S. Robson, and C. J. Greene. 1997. Catch rate estimation for roving and access point surveys. North American Journal of Fisheries Management 17(1):11-19.

Ricker, W. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can 191:382.

Schneider, J. C. 2000. Manual of fisheries survey methods II: With periodic updates. Michigan Dept. of Natural Resources, Fisheries Division.

Schramm Jr, H., and V. Mudrak. 1994. Essay: Beneficial aspects of put-and-take trout stocking. Fisheries-Bulletin of the American Fisheries Society 19(8):6-7.

Sorensen, P. W., T. Essington, D. E. Weigel, and J. R. Cardwell. 1995. Reproductive interactions between sympatric brook and brown trout in a small Minnesota stream. Canadian Journal of Fisheries and Aquatic Sciences 52(9):1958-1965.

Stiller, J.C. 2011. Common Merganser (*Mergus merganser*) Effects on Hatchery-reared Brown Trout (*Salmo trutta*) and Spring Movements of Adult Males in Southeastern New York, USA. Masters thesis. State University of New York, College of Environmental Science and Forestry, Syracuse, NY. 38 pages.

Sullivan P.J. and Kraft, C. E. 2005. A review of the philosophy, data, and modeling that supports the NYSDEC catch rate oriented trout stocking program. Cornell Fisheries Research Program, Ithaca, NY, USA.

Taylor, M. J., and K. R. White. 1992. A Meta-Analysis of Hooking Mortality of Nonanadromous Trout. North American Journal of Fisheries Management 12(4):760–767.

Treska, T. R., P. J. Sullivan, and C. E. Kraft. 2005. Regional analysis of trout.exe Model predictions relative to survey estimates. Report to NYSDEC, Ithaca, NY.

Van Vooren, A. 1995. The roles of hatcheries, habitat, and regulations in wild trout management in Idaho. Uses and Effects of Cultured Fishes in Aquatic Ecosystems 512-517.

Walters, C. J. 2007. Is adaptive management helping to solve fisheries problems? AMBIO: A Journal of the Human Environment 36(4):304-307.

Wehrly, K. E., T. O. Brenden, and L. Wang. 2009. A comparison of statistical approaches for predicting stream temperatures across heterogeneous Landscapes. Journal of the American Water Resources Association 45(4):986-997.

Young, R. G., and J. W. Hayes. 2004. Angling Pressure and Trout Catchability: Behavioral Observations of Brown Trout in Two New Zealand Backcountry Rivers. North American Journal of Fisheries Management 24(4):1203–1213.

Zimmerman, J. K. H., and B. Vondracek. 2007. Brown trout and food web interactions in a Minnesota stream. Freshwater Biology 52(1):123-136.

Appendix A. Habitat

Habitat

The NYSDEC trout stocking program is based on the catch rate oriented trout stocking (CROTS) model, which combines estimates of angling pressure, wild trout population abundance, and stream carrying capacity to calculate a number of fish to stock in a given stream segment. The goal of the CROTS model is to provide anglers with a catch rate of one fish per two hours of fishing. The CROTS model has been a useful management tool for characterizing stream condition, formulating appropriate management procedures, implementing management actions and monitoring angler and ecosystem responses (Sullivan and Kraft 2005). Stream fish populations can be limited by either biotic (competition, predation, etc.) or abiotic (limiting habitat, environmental constraints, etc.) factors. The goal of the CROTS habitat assessment is to exploit the space between carrying capacity and wild trout abundance (Figure 1). In the CROTS model, biotic and abiotic data are collected rapidly in the field and estimates of carrying capacity (K) are calculated using a mixed quantitative and qualitative points-based ranking system. The CROTS habitat assessment system assumes that a stream's carrying capacity is based on the model: $H \times F \times N$, where H = habitat, F= fertility, and N= non-trout (i.e., abundance of competitors). CROTS then divides streams into high carrying capacity (A streams) or low carrying capacity (B streams).

Based on the parameters estimated in this study, the A and B stream dichotomy is sound; as fish in B streams exhibited higher apparent mortality than in A streams. However, given the high apparent mortality rates exhibited by wild and stocked trout in these systems (both A and B streams), fish populations are likely not reaching K (i.e., exhibiting density independent mortality). Therefore, it might be more appropriate to first test for density dependence (i.e., biotic limitation via intraspecific competition) in the system. This is the most important limiting factor for consideration in stream stocking programs, because a density dependent wild fish population will be more affected by sympatric stocked fish of the same species than density independent populations. If a density dependent relationship is found, it then becomes important to examine which habitat features are most limiting to population abundance, growth, or survival. The objectives of this study were to: 1) test for density dependence using spawner recruit models and 2) determine which habitat factors might be most limiting to populations using generalized additive models (GAMS). The results of this study will provide insight into factors limiting trout abundance and survival in streams and provide a quantitative performance ranking of habitat metrics that could be incorporated into the CROTS model.

Methods

Objective 1

We used non-linear Beverton-Holt and Ricker spawner-recruit models to test for density dependence in the wild trout populations of the nine FOST streams. The recruitment curve developed by Beverton Holt (1957) assumes that intraspecific competition for a limited resource will cause recruits to initially increase then decline as an asymptotic value (K) is approached. The model can be written as:

$$R = \alpha S \mathbin{/} 1 + \beta S$$

where R is recruit abundance, α is the density independent coefficient, S is spawner abundance and the β coefficient determines the level of density dependence. The Ricker spawner-recruit model (1954)

assumes the relationship might be dome shaped at higher levels of spawner abundance due to overcompensation processes such as cannibalism. The Ricker model can be written as:

$$R = Se^{\alpha - \beta S}$$

We then used Akaike's Information Criterion (Akaike 1973) (*AIC= -2ln(L) +2K*, where *L* is the model likelihood and *K* is the number of parameters), which balances model fit and parsimony (precision) to evaluate model performance. We then used our best model (lowest AIC) to determine the shape of the spawner-recruit relationship. Models less than two ΔAIC (change in AIC value) apart were considered to perform equally (Burnham and Anderson 1998). In order to parameterize the model, we first had to estimate the length at age for wild trout in New York streams to determine recruit and spawner abundance. Stream trout typically reach maturity after age one, so fish above the upper limit of age zero were considered spawners and below were considered recruits. Using the Statewide Fisheries Database (SWFDB), we developed the length at age relationship using records for over 25,000 wild brown trout, 6,895 rainbow trout, and 3,324 brook trout. This relationship allowed us to separate spawners and recruits based on length, rather than aging each fish (Figure 2). Methods for fish abundance estimation were described above in the "Population Estimates" section of this report.

Objective 2

We began our assessment of carrying capacity by delineating mesohabitat units within representative stream reaches, stratified to encompass longitudinal variation (i.e., upstream, midstream, and downstream), on each of the nine study streams (Bain and Stevenson 1999). Stocked stream segments in these streams ranged from approximately 3km to 26km in length with mean wetted channel widths (MCW) ranging from 4m to 35m. Reach lengths were 10 times the MCW for each reach to encompass at least one complete meander wavelength; thereby ensuring that all habitat types are represented within the reach (Leopold et al. 1964). Transects were spaced every two MCW for stream reaches > 5 m wide and every three MCW for stream reaches < 5m wide (Simonson et al. 1994). Reach start locations (i.e., upstream, midstream, and downstream) were concurrent with reaches sampled by the NYSDEC for trout population estimates in 2011-2013. Channel unit type was determined using methods outlined in Bain and Stevenson (1999). Channel unit surface area (m^2) was mapped using GPS (Trimble Juno) (Figure 3). Within each channel unit, we measured microhabitat variables (Table 1) at five equidistant points (Fore et al. 2007) on transects. Habitat assessments were conducted during the summer base flow period in 2012 and 2013, which is a limiting period of available habitat for trout (Sotiropoulos et al. 2006).

We developed stream trout- habitat relationships using generalized additive models (GAMs; Guisan et al. 2002) at the reach scale for the nine FOST study streams using multiple meso- and microhabitat variables. GAMs provide greater flexibility for modeling fish habitat relationships than general linear models because the distribution of the dependent variable can be non-normal and variables do not have to be continuous, allowing for quantitative prediction of variable thresholds in habitat selection. GAMs produce resource selection functions that are data driven rather than being constrained to follow a particular distribution (Jowett 2008). This flexibility makes GAMs well suited to predict how abundance or survival varies with a given habitat variable (i.e. discharge, stream temperature, etc.).

GAMs work by predicting dependent variable values from a linear combination of predictor variables, which are connected to the dependent variable via a “link function” in a process known as non-parametric smoothing. There are two separate iterative operations involved in the algorithm, called the outer and inner loop. The purpose of the outer loop is to maximize the overall fit of the model, by minimizing the overall likelihood of the data given the model (similar to maximum likelihood estimation). The purpose of the inner loop is to refine the scatterplot smoother. The smoothing is performed with respect to the partial residuals; i.e., for every predictor k, the weighted fit is found that best represents the relationship between a given variable and the residuals computed by removing the effect of all other predictors. The iterative estimation procedure continues to loop through the data until the likelihood of the data given the model cannot be improved. A common criticism of GAMs is that their flexibility allows for the potential to over-fit the data by applying an overly complex model (with many degrees of freedom) to the data. The issue can be avoided by using an AIC model selection approach (described above) which reduces over-fitting by penalizing each additional parameter in a model. We also limited over-fitting by restricting our candidate model set to biologically justified variables and interactions (Table 2).

Results

Objective 1

Using relative abundance data calculated from the SWFDB and the FOST population estimates, we were able to fit a spawner recruit relationship for the nine study streams for 16 years over a 25 year period (1988-2013). The Ricker model (AIC = 185.17) performed much better than the Beverton-Holt model (AIC= 189.17), with the models more than 2 ΔAIC's apart. The β coefficient for the Ricker model was not significant ($\beta = 0.002$; $p < 0.1$), indicating the absence of a density dependent relationship. Furthermore, the α coefficient was significant ($\alpha = 0.300$, $p< 0.05$), providing evidence that trout density is regulated independently of intraspecific limiting factors (Figure 4). This indicates that when trout densities were high, so was the estimated carrying capacity as evidence by density of recruits. We tested this relationship further by dividing the data into years where stocked trout abundance was highest and lowest at the 0.50 quantile. We then plotted how the relationship changed as a function of stocked trout abundance. We found that in years of the highest stocked trout abundance, the estimated carrying capacity of the systems was also higher (Figure 5) ($p < 0.05$).

Objective 2

We modeled trout abundance (density (fish/acre)) and instantaneous apparent mortality (Zn) as a function of 12 multiple scale habitat factors (Figures 6 and 7; Table1) using GAM models. The best single parameter for explaining abundance was conductivity (Table 2) while mean summer low flow discharge was the best performing single parameter at explaining variation in Zn (Table 2). The contribution of conductivity to abundance model fit was compounded by mean summer temperature, yielding the best performing model out of the candidate model set (Table 2, Figure 8). When velocity and conductivity were modeled interactively, the two parameters provided the highest contribution to Zn model fit (Table 2, Figure 9). Somewhat surprisingly, percentage pool area of a reach appeared to have a negative relationship with Zn, though the relationship was not significant, though this could be due to the seasonality of habitat usage interacting with the seasonality of our sampling.

Discussion

The stock recruitment model coefficient for density independence α was significant, while the density dependent coefficient β was not significant. Furthermore, when stocked trout abundance was high, we also saw higher abundances of wild trout. Taken together, our findings provide evidence that trout in these systems are more limited by abiotic factors (habitat limitation) than intraspecific competition, cannibalism, or other biotic factors. Since density independent relationships appear to be operating in these systems, it remains important to examine which habitat features are most limiting to population abundance and survival.

Conductivity was included in several of the top models explaining both abundance and Zn and was the best single parameter for explaining abundance. The quantity of nutrients available in stream water is directly proportional to the conductivity; therefore our results show that basal resource limitation (i.e., nutrients) may have ramifications through the entire food web all the way up to apex predators such as trout. Although an interactive model with velocity and conductivity was the top model for explaining survival, summer low flow discharge level was the best single parameter highlighting the importance of maintaining a natural flow regime. Mean summer temperature was in the top model for abundance, indicating that high summer temperatures can be an important limiting factor for stream trout abundance.

Fortunately, all of the top model variables are already measured or estimated using the existing CROTS carrying capacity estimation protocol suggesting that the current model is adequate to assess and rank relative habitat quality among stocked streams. However, many of the parameters included in the current CROTS model did not explain much of the variation in the data and may not need to be included in future protocols. Additionally, although conductivity is currently measured in CROTS, it may not be adequately weighted in the model. Conductivity could potentially be more heavily weighted as it appears to be the best proxy variable for habitat quality. Overall, it appears that the CROTS habitat assessment is not a key factor in the discrepancy between previous model and empirically collected population estimates and likely does not require a major overhaul; however, based on our findings, some of the current habitat variables collected in assessments may be superfluous and could be removed.

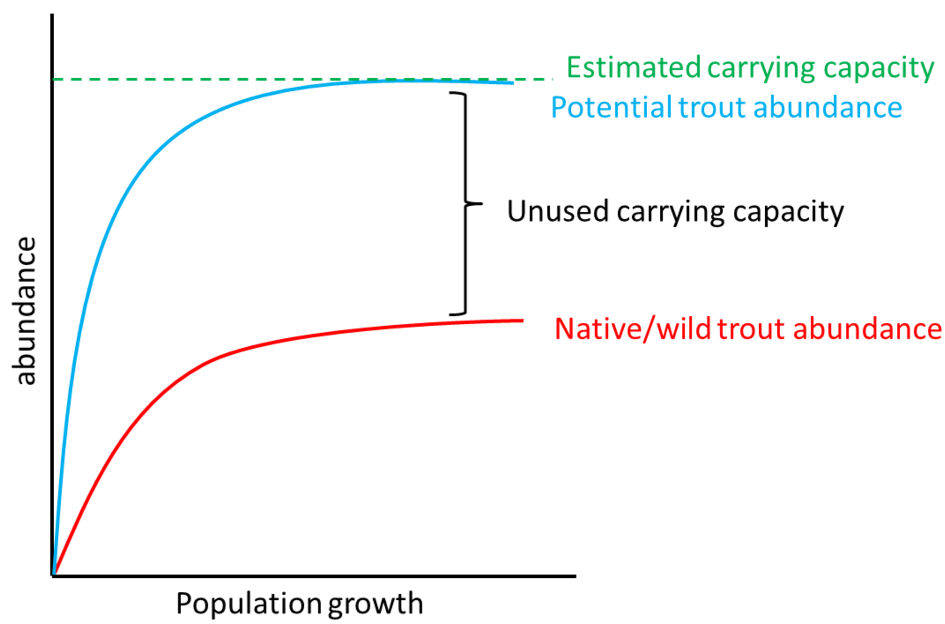


Figure 1.Hypothetical “unused” carrying capacity model used in CROTS.

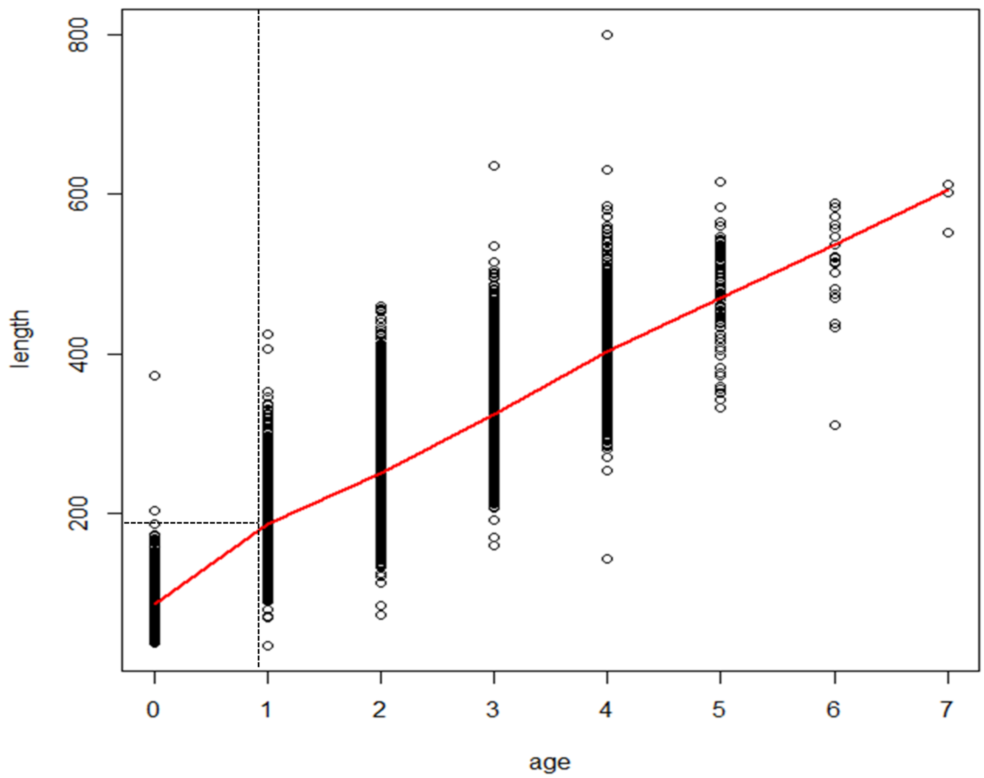


Figure 2.Wild trout age-length relationship.

Table 1. Habitat variables incorporated into models.

Scale	Variable	Sources*
Microhabitat	Water depth (m)	Fausch et al. 1988; Armstrong 2003
	Stream velocity(m s^{-1}) / discharge (ls^{-1})	Fausch 1988; Armstrong 2003
	Substrate (embededness/Wentworth)	Fausch 1988; Armstrong 2003
	% Cover (overhead + instream)	Fausch 1988; Armstrong 2003
	Water temperature (C˚)	Fausch 1988; Armstrong 2003
	Large woody debris (LWD)	Kraft and Warren (2003); Montgomery and Piegay (2008)
	Dissolved Oxygen (mg L^{-1})	Fausch 1988

	Conductivity(µS/cm; pH; alkalinity (mg L^{-1})	Fausch 1988
Mesohabitat	Channel unit surface area	Fausch 1988; Parasiewicz 2007; Cramer and Ackerman 2009

*Fausch et al. (1988) included 99 studies; Armstrong et al. (2003) incorporated approximately 14 models.

Table 2.Abundance and mortality models ranked by variable performance.

Abundance Models	**df**	**AIC**	**Effect Direction**	**Significance**
mean temp + conductivity	11	149.39	+	***
ph + conductivity	5	162.31	+	***
conductivity	5	165.84	+	***
max temp+ conductivity	7	167.11	+	***
velocity+conductivity	6	167.29	+	***
depth+velocity	9	179.78	+	***
mean temp + velocity	6	187.56	+	***
velocity	6	187.90	+	***
pH	3	191.96	+	***
discharge	3	200.96	+	*
% riffle area	6	202.96	-	
LWD count	5	203.56	+	
dissolved oxygen	5	204.60	+	
max temp	3	204.89	-	
reach volume	3	205.12	+	
depth	3	206.12	-	
pool	3	206.17	-	
% overhead cover	3	206.36	-	
mean temp	3	206.64	+	
substrate	3	207.12	-	
Survival Models				
velocity + conductivity	14	-183.78	+	***
discharge	9	-156.69	+	***
conductivity	11	-146.44	+	***
ph + conductivity	8	-139.86	+	***
maxtemp + conductivity	8	-139.58	+	***
temp + conductivity	8	-139.29	+	***
depth + velocity	8	-138.00	+	***
velocity	4	-135.36	+	***

temp + velocity	5	-134.22	+	***
volume	10	-125.47	+	***
ph	3	-102.65	+	*
% pool area	3	-101.70	+	
depth	4	-99.55	+	
substrate	3	-98.61	+	
mean temp	3	-98.60	+	
% riffle area	3	-98.31	-	
% overhead cover	4	-98.22	+	
max temp	3	-97.73	-	
lwdshelter	3	-97.50	-	
odo	3	-94.97	-	

* Significance codes = 0 '***' 0.001 '**' 0.01 '*' 0.05 '*ns' not significant*

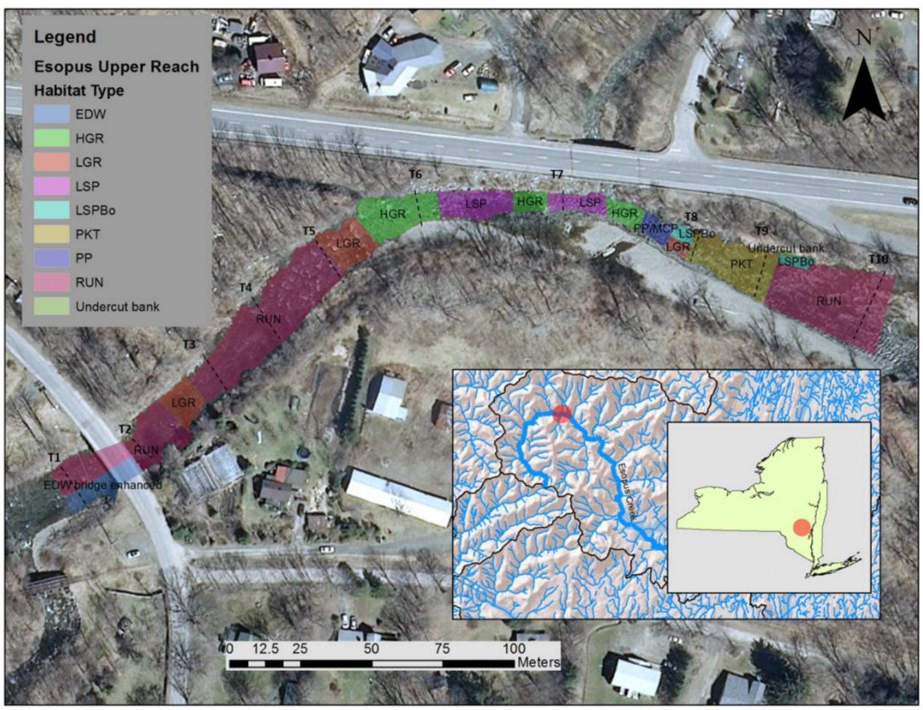


Figure 3. Example of a single reach scale mesohabitat map incorporating data on channel geomorphic habitat unit type, discharge, substrate, embededness, depth, instream and overhead cover, water chemistry data, temperature, land use, and riparian vegetation.

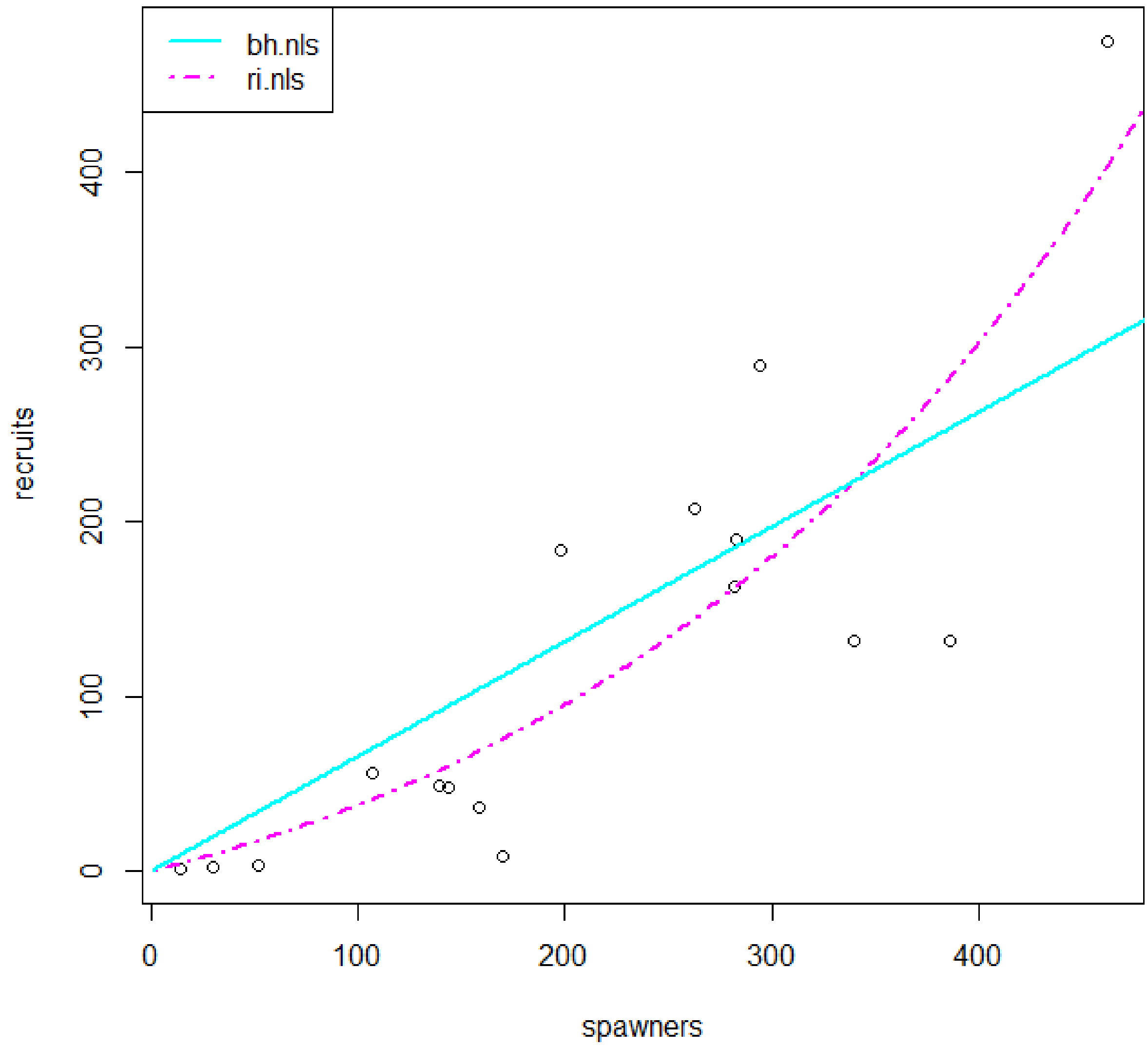


Figure 4.Beverton-Holt and Ricker model fit for FOST study streams from 1998-2012. Relationship indicates that wild trout populations are not density dependent.

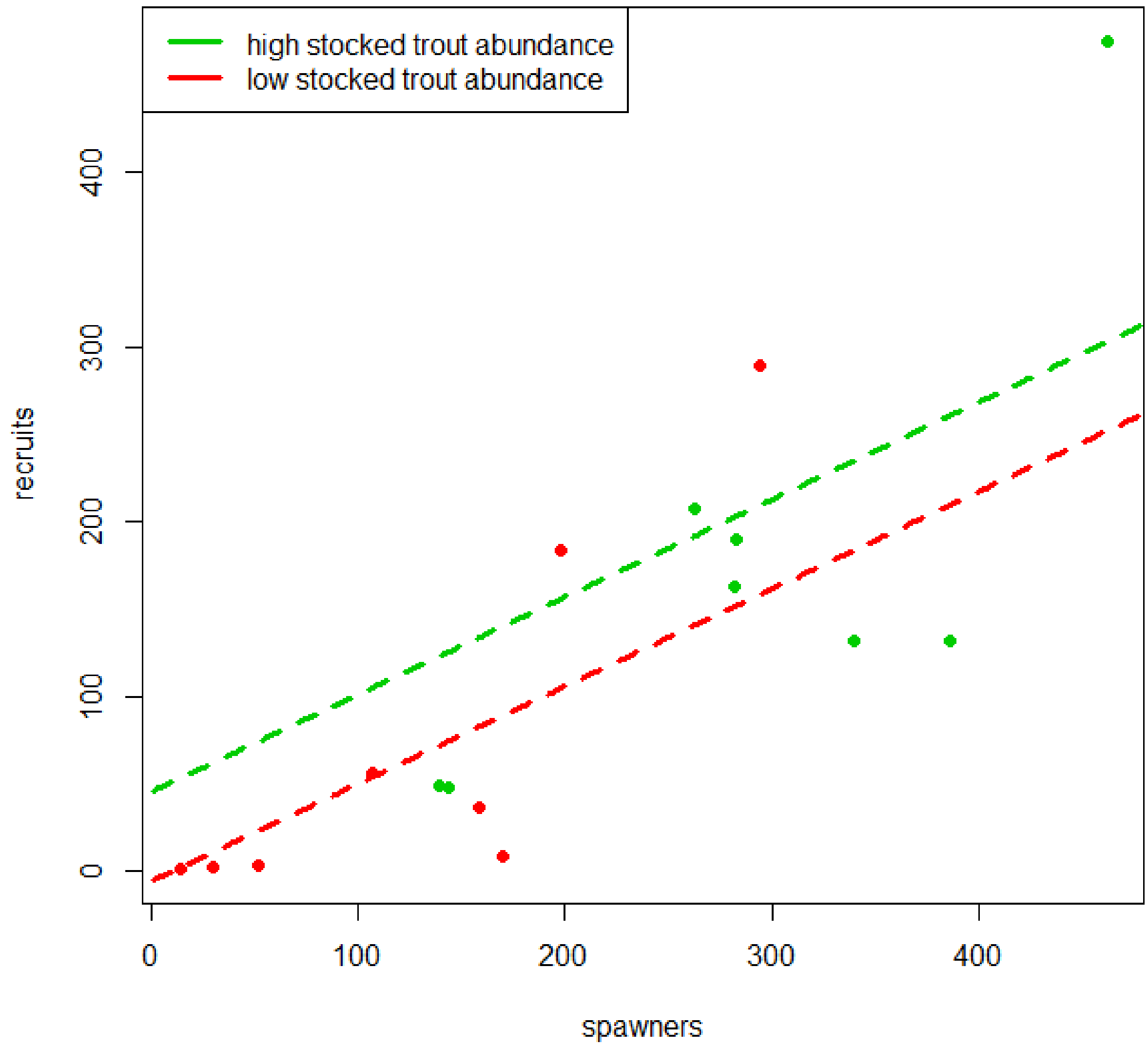


Figure 5.Carrying capacity shown as a function of stocked trout abundance. Capacity was higher when stocked trout abundance higher, indicating density independence (i.e., system is more limited by abiotic rather than biotic factors).

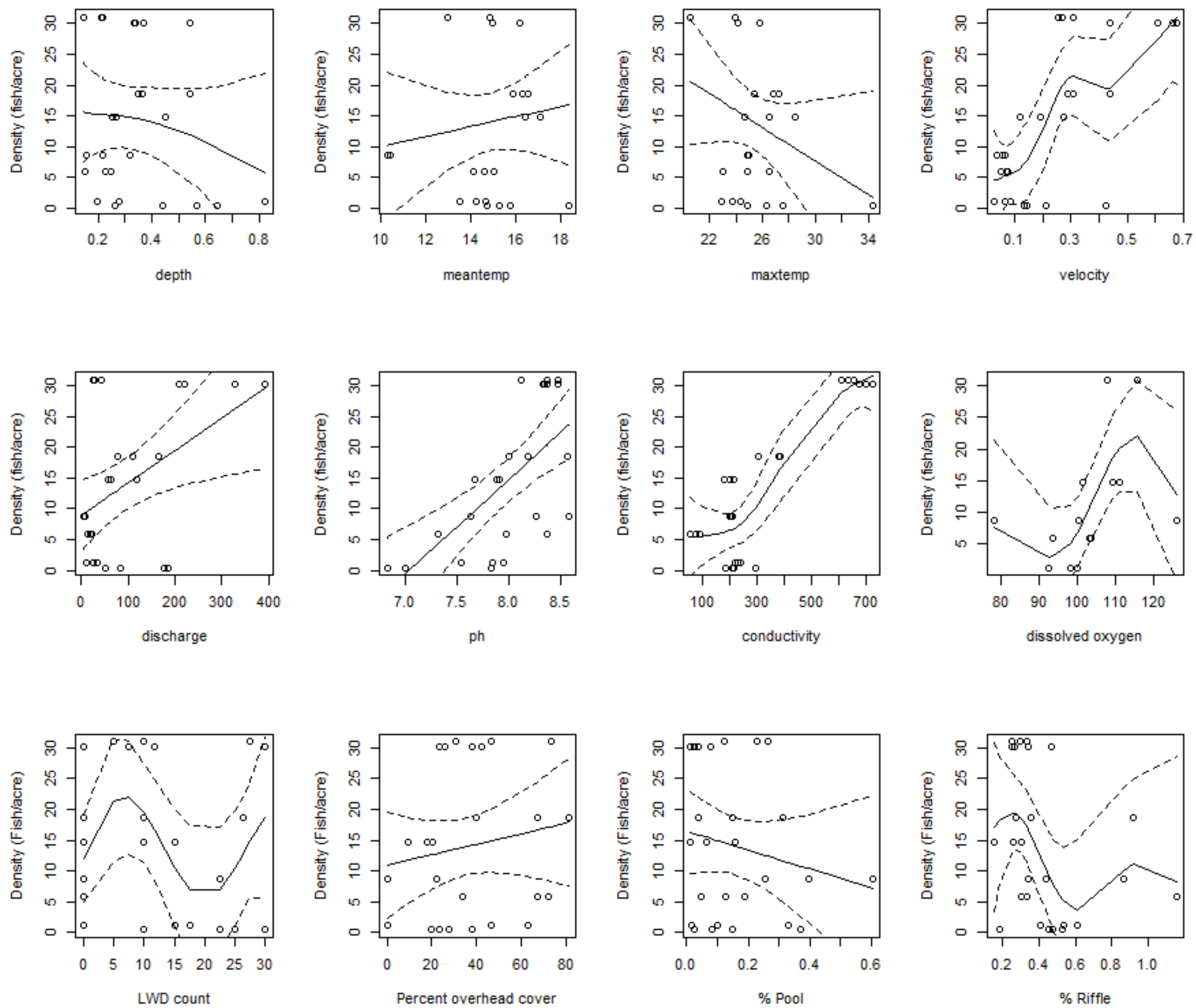


Figure 6.Relationship of trout abundance (fish/acre) to habitat parameters using Generalized Additive Models (GAMs).

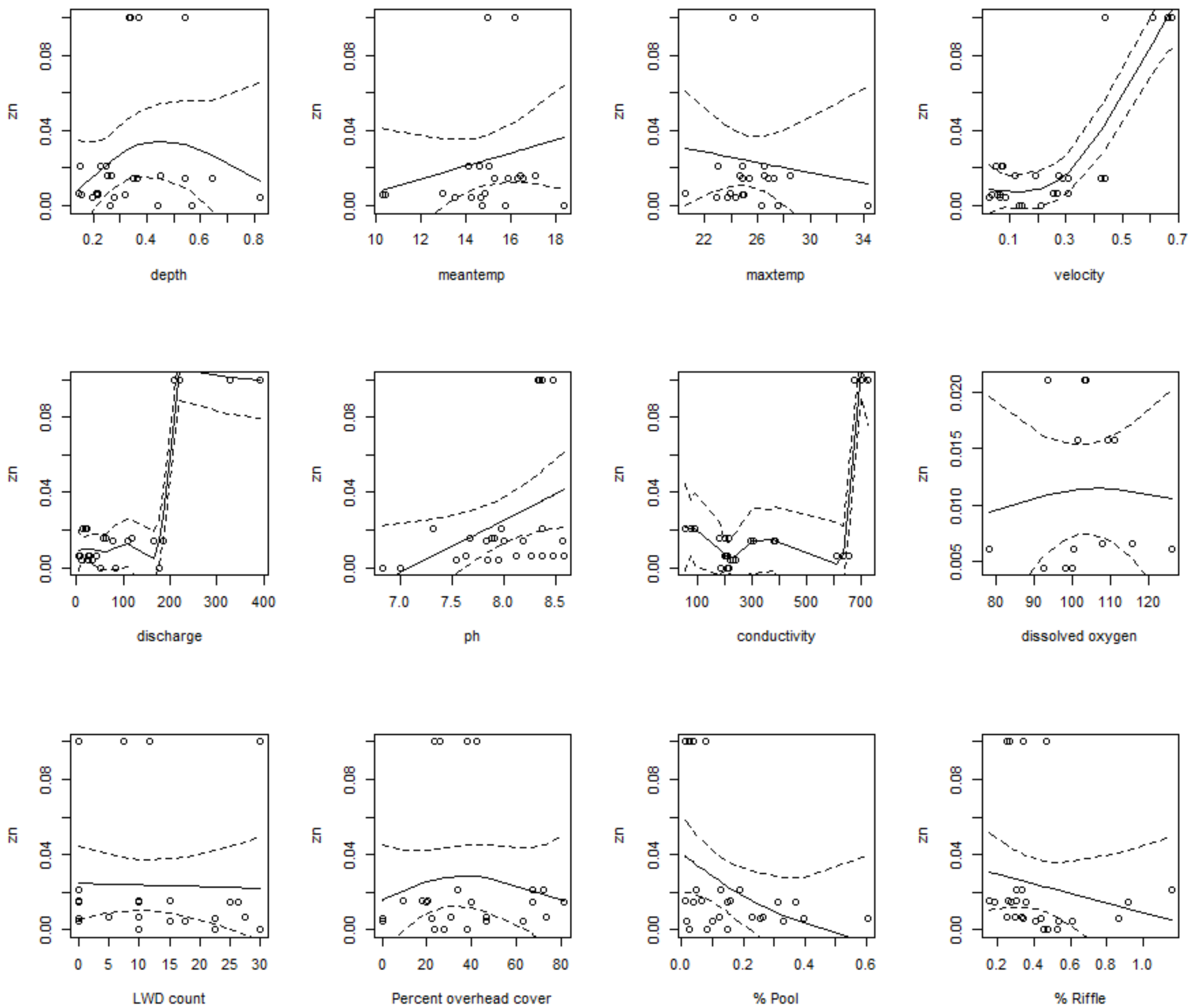


Figure 7.Relationship of instantaneous apparent mortality (Zn) to habitat parametersusing Generalized Additive Models (GAMs).

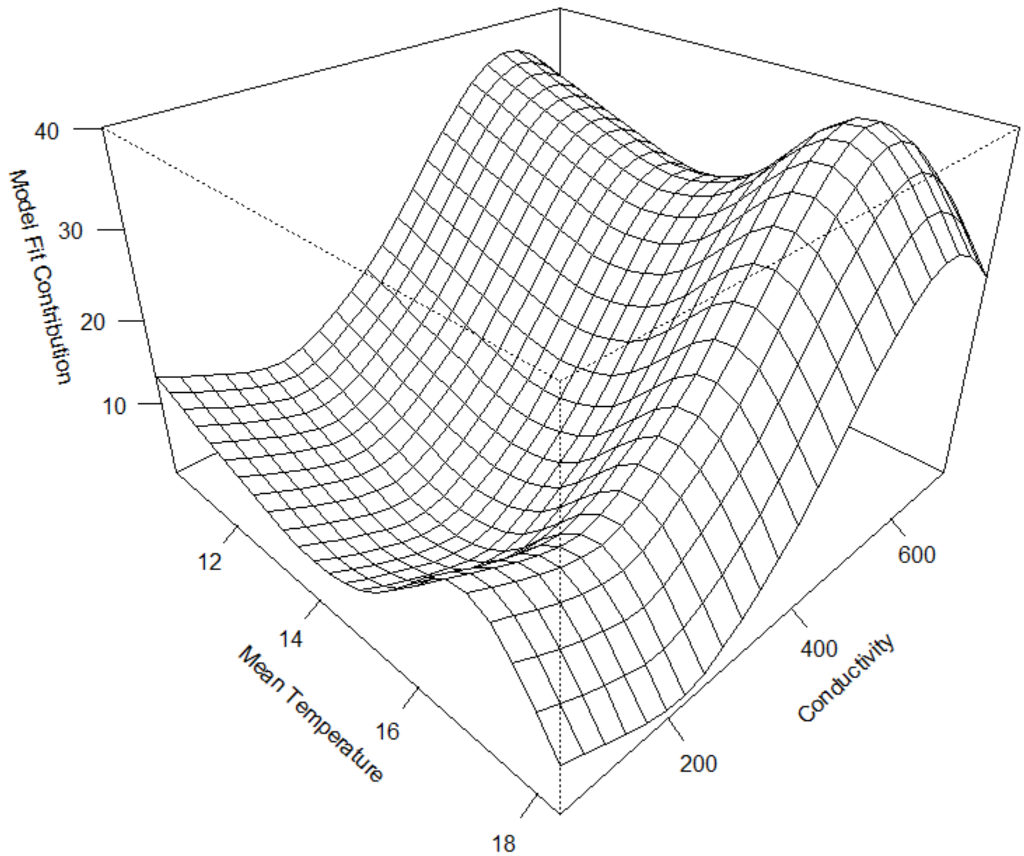


Figure 8. Top combined variable abundance model (mean temperature+conductivity) plotted as function of contribution to model fit.

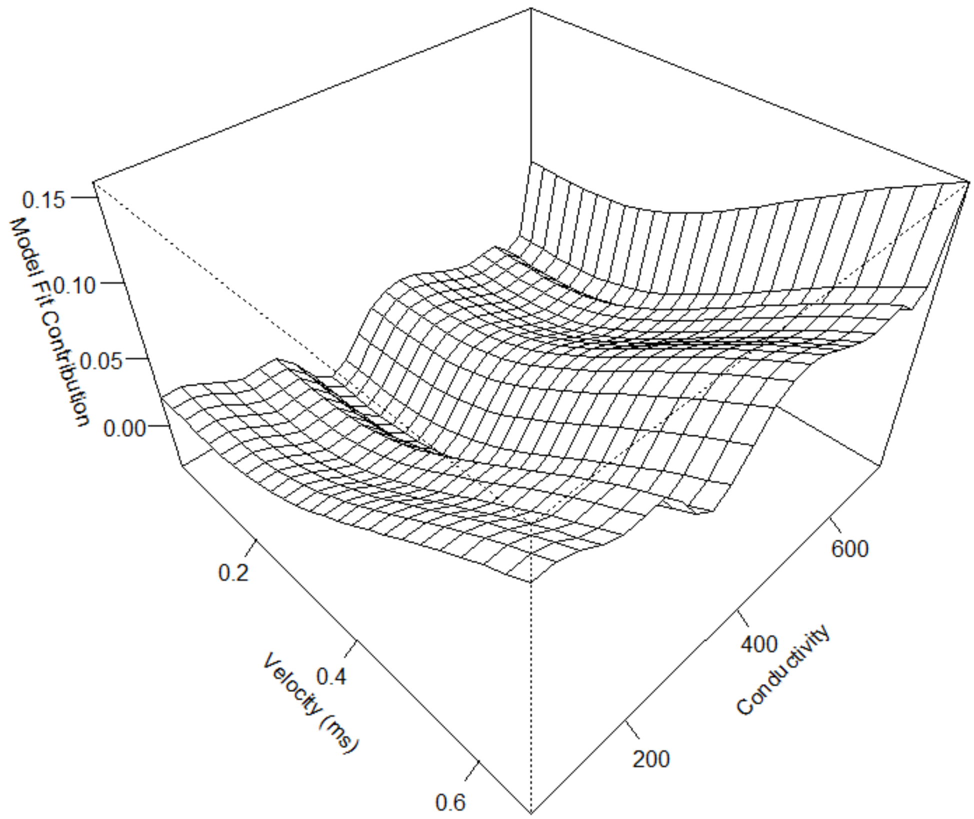


Figure 9. Top combined variable mortality model (mean temperature+conductivity) plotted as function of contribution to model fit.

Appendix A References

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. Proceedings of the Second International Symposium on Information Theory :267-281.

Armstrong, J., P. Kemp, G. Kennedy, M. Ladle, and N. Milner. 2003. Habitat requirements of atlantic salmon and brown trout in rivers and streams. Fisheries Research 62(2):143-170.

Bain, M. B., and N. J. Stevenson. 1999. Aquatic habitat assessment : Common methods. American Fisheries Society, Bethesda, Md.

Burnham, K., and D. Anderson. 1998. Model selection and inference: An information-theoretic approach. Spring-Verlag, New York .

Cramer, S. P., and Ackerman, N. K. 2009. Prediction of stream carrying capacity for steelhead: The unit characteristic method. Proceedings of the American Fisheries Society Symposium 71:255-288.

Fausch, K. D., C. L. Hawkes, and M. G. Parsons. 1988. Models that predict standing crop of stream fish from habitat variables: 1950-85. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Report PNW-GTR-213, Portland, OR.

Fore, J. D., D. C. Dauwalter, and W. L. Fisher. 2007. Microhabitat use by smallmouth bass in an ozark stream. Journal of Freshwater Ecology 22(2):189-199.

Guisan, A., T. C. Edwards, and T. Hastie. 2002. Generalized linear and generalized additive models in studies of species distributions: Setting the scene. Ecological Modelling 157(2):89-100.

Jowett, I. G., and A. J. H. Davey. 2007. A comparison of composite habitat suitability indices and generalized additive models of invertebrate abundance and fish presence–habitat availability. Transactions of the American Fisheries Society 136(2):428-444.

Kraft, C. E., and D. R. Warren. 2003. Development of spatial pattern in large woody debris and debris dams in streams. Geomorphology 51(1–3):127-139.

Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. Fluvial processes in geomorphology. W.H. Freeman, San Francisco.

Montgomery, D. R. 2008. A simple alphanumeric classification of wood debris size and shape. Stream Notes Rocky Mountain Research Station .

Parasiewicz, P. 2007. The MesoHABSIM model revisited. River Research and Applications 23(8):893-903.

Simonson, T. D., J. Lyons, and P. D. Kanehl. 1994. Quantifying fish habitat in streams: Transect spacing, sample size, and a proposed framework. North American Journal of Fisheries Management 14(3):607-615.

Sotiropoulos, J., K. Nislow, and M. Ross. 2006. Brook trout, salvelinus fontinalis, microhabitat selection and diet under low summer stream flows. Fisheries Management and Ecology 13(3):149-155.

Appendix B. Thermographs

Temperature can be an important limiting factor for salmonid populations. Adult brown trout typically do not optimally feed at temperatures higher than 19.5˚C and mortality can occur at temperatures above 25˚C (Elliott 1981). Brook trout require even lower stream temperatures than brown trout (Hokanson et al. 1973). A study of 36 rivers in Wyoming showed that trout productivity was optimal between 12.6 and 18.6˚C (Binns and Eiserman 1979). Water temperature can be measured at stream locations or interpolated at multiple scales in stream networks (Gardner et al. 2003) making it an easy parameter to monitor. Clearly, temperature is an important component for models attempting to predict stream carrying capacity for salmonids.

The regional biologists and managers on the trout team hypothesized that maximum summer temperatures could be a primary driver of stocked trout apparent mortality. In order to investigate the relationship between stream temperature and fish mortality, we deployed HOBO temperature data loggers in each stream. Each stream had a minimum of two temperature loggers, one at the upstream end of the stocked reach and another at the downstream end. Loggers were placed in the thalweg of the stream in a well fixed fastwater habitat unit to ensure constant water turnover, providing a realistic estimate of average stream temperature. Temperatures were logged hourly from April to October in 2012 and 2013.

We averaged hourly temperatures to calculate a mean daily temperature (Figures 1 and 2) in 2012 and 2013. Unfortunately, due to a low water year in 2012, the temperature loggers on Meads Creek became exposed to air periodically after May 22nd, therefore only temperatures prior to that date were useable. All study streams experienced maximum temperatures above the optimal upper thermal range of brown trout for extended periods during the summer months (Figures 1 and 2). We then determined the maximum and average seasonal stream temperatures. We calculated a mean instantaneous apparent mortality (Zn) for each stream as:

$$Zn = [\frac{loge(Nt) - loge(Nt)}{It}]$$

where N_t = fish at 1st sampling, N_{t+1}= fish at sampling interval, and I_t = period between release and sampling. We plotted Zn against average and maximum stream temperature and developed the relationship using a linear model (Figures 3 and 4) for both study years. The relationships were not significant between Zn and average stream temperature (P= 0.411) or maximum stream temperature (P= 0.619). R squared values were also low for the both relationships 0.33 and 0.04

for average and maximum stream temperature respectively. Our findings reveal the lack of a strong relationship between stocked trout mortality and stream temperature. This is likely due to the availability of microhabitat thermal refugia where temperatures remained below critical maximum. Given the results from this study, we do not necessarily recommend incorporating hourly stream temperature monitoring on stocked streams as part of the CROTS protocol. However, in the event of rapid loss (mortality or emigration) of stocked fish within a reach, it might be advisable to monitor stream temperatures as it appears that many streams do experience temperature above the optimal thermal range of brown trout and the relatively low operational expense of implementation.

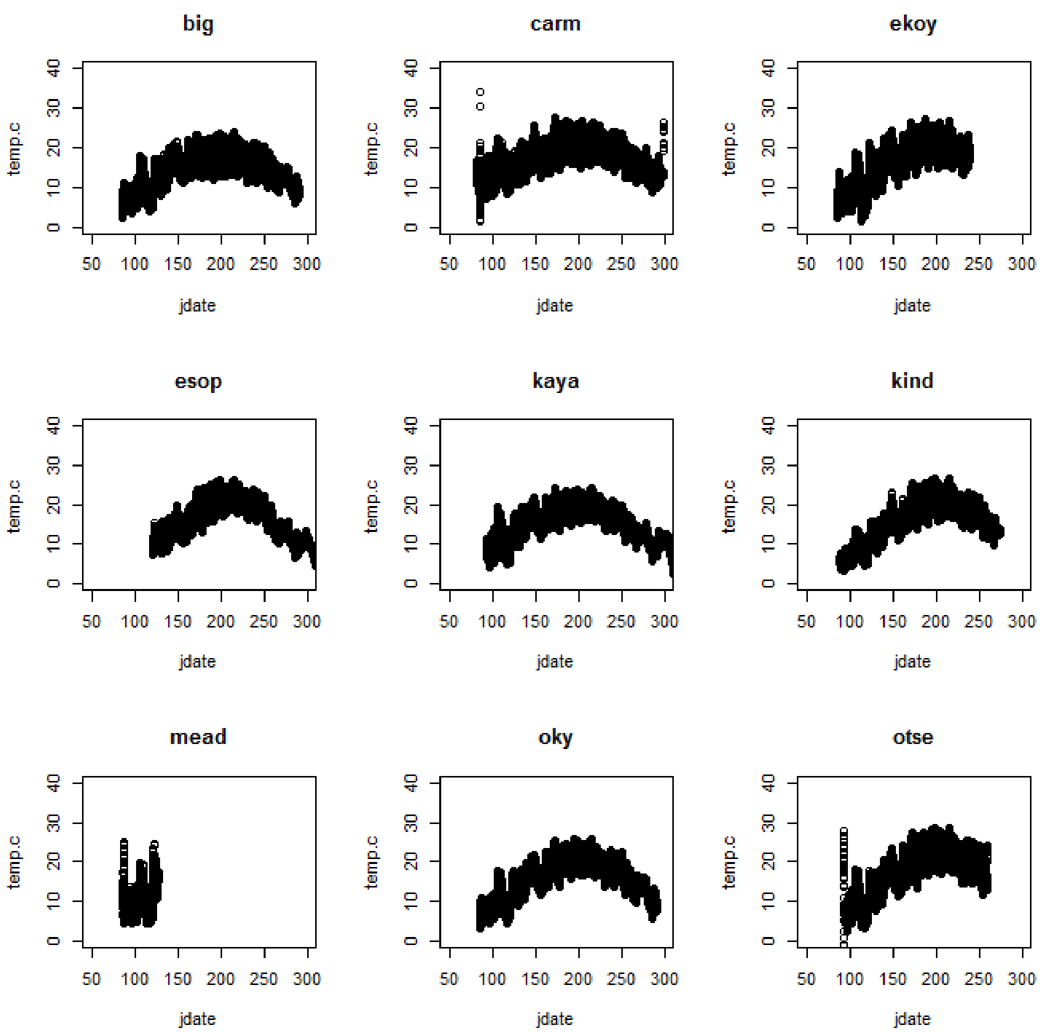


Figure 1.Thermograph data 2012. (Meads thermograph was dewatered)

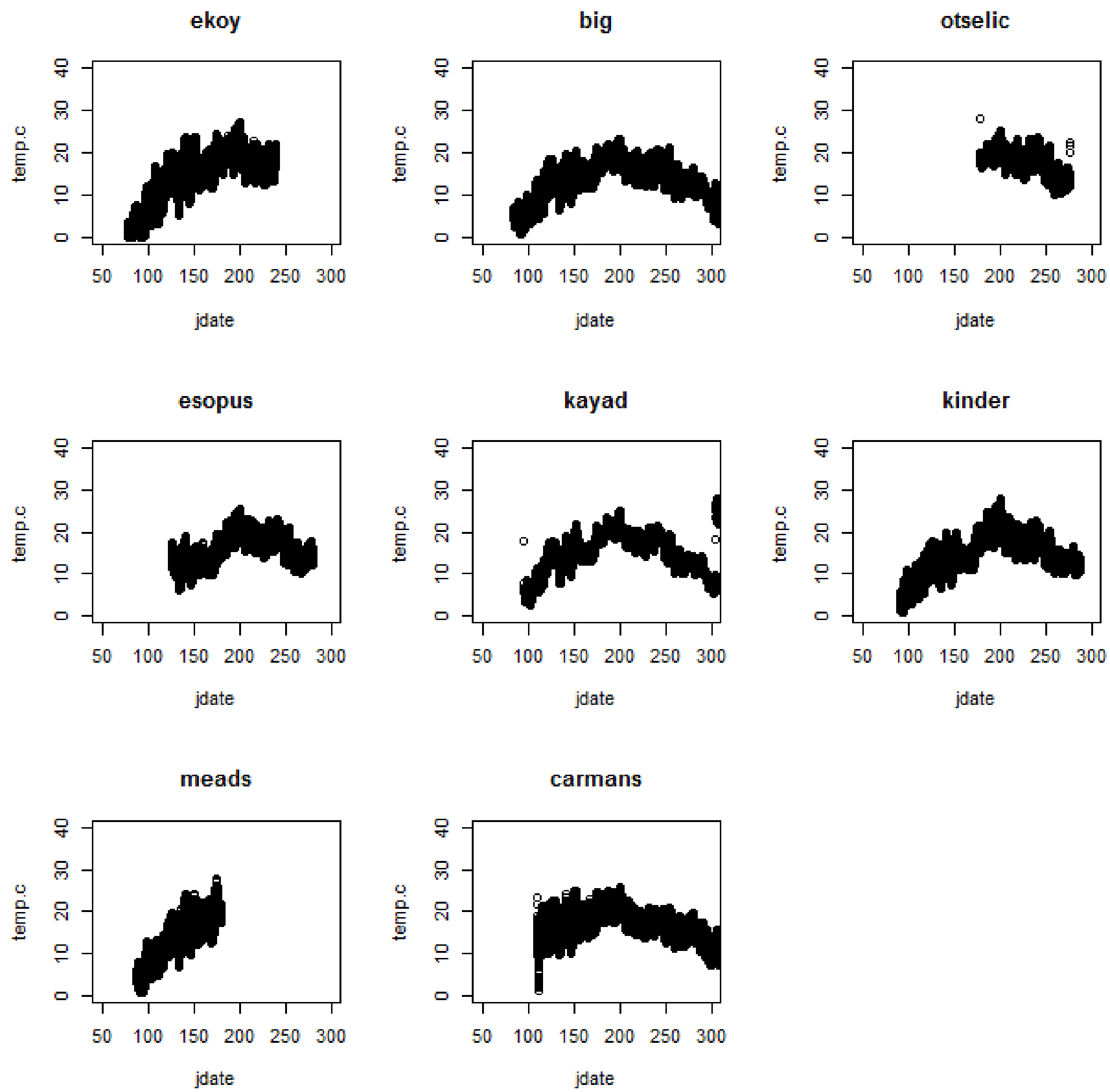


Figure 2. 2013 thermograph data.(Oriskany temperature loggers were washed away in summer floods)

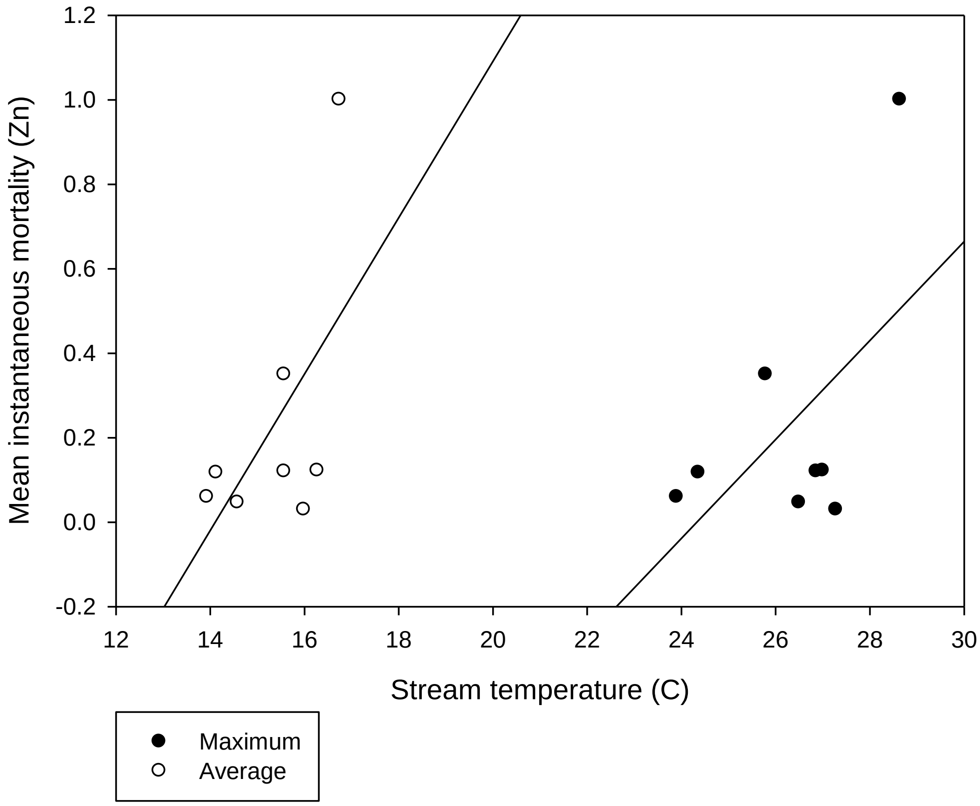


Figure 3. Temperature-mortality relationship 2012

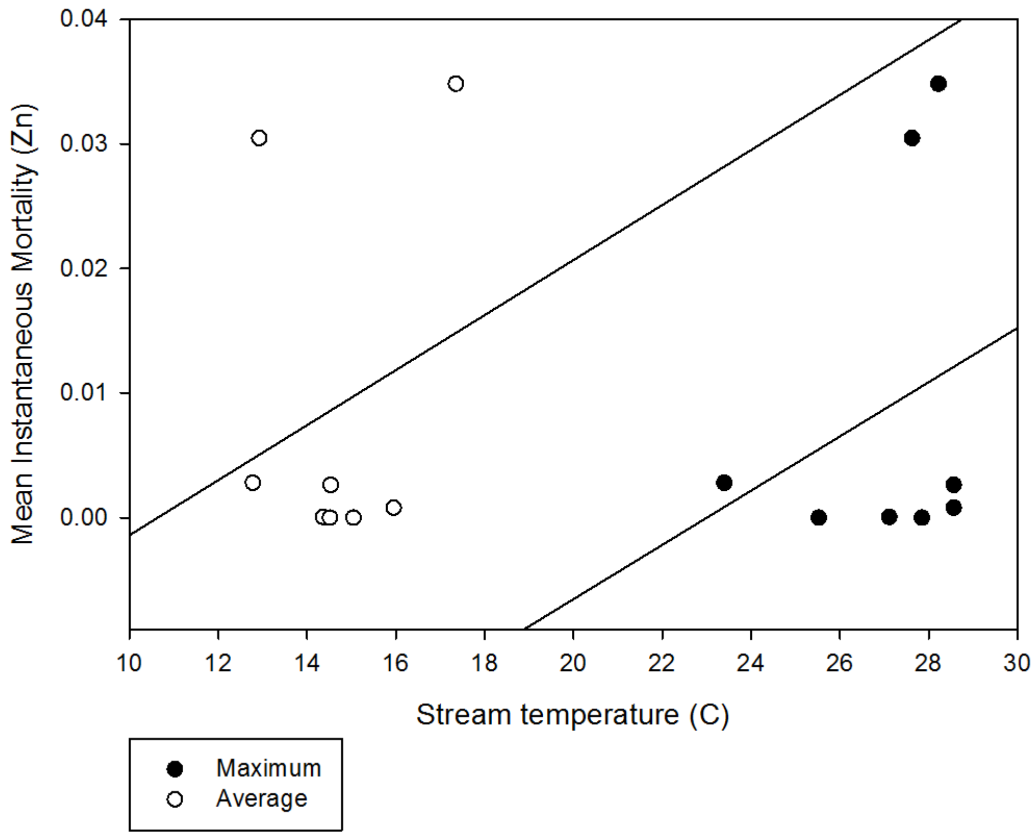


Figure 4.Temperature-mortality relationship in 2013.

Appendix B References

Binns, N. A., and Eiserman, F. M. 1979. Evaluation of fluvial trout habitat in rocky mountain Streams1. Proceedings of the The Mitigation Symposium: A National Workshop on Mitigating Losses of Fish and Wildlife Habitats, July 16-20, 1979, Colorado State University, Fort Collins, Colorado 65:361.

Elliott, J. 1981. Some aspects of thermal stress on freshwater teleosts. Stress and Fish 209:245.

Gardner, B., P. J. Sullivan, and A. J. Lembo Jr. 2003. Predicting stream temperatures: Geostatistical model comparison using alternative distance metrics. Canadian Journal of Fisheries and Aquatic Sciences 60(3):344-351.

Hokanson, K. E. F., J. H. McCormick, B. R. Jones, and J. H. Tucker. 1973. Thermal requirements for maturation, spawning, and embryo survival of the brook trout, salvelinus fontinalis. Journal of the Fisheries Board of Canada 30(7):975-984.

Appendix C. Catch cards-complete vs. incomplete trips

The estimation of angler effort hours for this study employed on-site interview methods (i.e., roving creel) that gathered information from incomplete fishing trips. Despite the established roving creel survey design, catch and harvest rates derived from incomplete trips may not accurately approximate those of completed trips. Keefe et al. (2009) found that catch and harvest rates were 32% and 39% higher respectively when estimated using incomplete trips. According to Pollock (1997), the mean-of-ratios (MOR) estimator is the accepted method for deriving catch rate from incomplete trips, whereas the ratio-of-means (ROM) estimator is the accepted method for deriving catch rate for completed trips. The rationale behind using the MOR estimator is that it is possible to show the large finite sampling variance associated with incomplete trips (Hoenig et al. 1997). Completed trips can be estimated using access surveys where logistically feasible or using angler diary programs or catch cards distributed to anglers at fishing sites associated with roving creel surveys. Pollock et al. (1997) suggested that to ensure proper use of the mean-of-ratios estimator, it should be validated in the field. Catch rates from incomplete and complete trips should be measured on the same sample of anglers. Specifically, anglers should be interviewed while fishing (incomplete trips) and again upon leaving the fishery (complete trips).

In order to satisfy the Pollock et al. (1997) criteria, we implemented an angler catch card program on streams utilizing the roving creel method in order to determine differences between complete and incomplete angler trips. Anglers were issued a postage paid postcard to be completed and returned to Cornell University. Each card was used to collect completed trip information including angler's name and contact information, party size, total time fished, and the total number of fish caught and released. Anglers that returned completed catch cards were entered to win a $100 lottery. The mean-of-ratios estimator is traditionally the accepted method for estimating catch rates from incomplete angler trips, while the ratio-of-means estimator is preferable for estimating catch rates from complete trips. Recent studies have demonstrated persistent bias when comparing the two estimators using catch data from incomplete and complete trips from the same sample of anglers and promoted the use of linear regression models to correct for apparent bias in catch rates based on incomplete trips. We contend that ordinary least squares linear regression is inappropriate to correct for this apparent bias because there is measurement error in both the response (e.g., catch rate estimated from complete trips) and explanatory (e.g., catch rate estimated from incomplete trips) variables, which underestimates the slope of the relationship. Alternatively, when both variables contain measurement error, model II regression methods provide less biased estimates. Though statisticians have been aware of the error in variables problem since the late 1880's and despite the availability of several methods for dealing with error in variables, relatively few ecologists or fisheries managers account for this problem, instead relying on linear regression irrespective of potential measurement error.

Methods

We compared the ratio-of means and mean-of-ratios estimators using OLS and model II (MA, RMA, SMA) regressions (Keefe et al. 2009; Legendre and Legendre 2012). While only one test is most appropriate for a given data structure, we provided estimates from all four tests for comparison purposes. We then used the regression equation (i.e., slope and intercept term) from each model to correct for the bias associated with estimates from incomplete trips by incorporating incomplete trip estimates into the linear model (Keefe et al. 2009). All statistical models and analyses were conducted using Program R Version 2.15.2.

Results

We conducted roving creel surveys for a total of 84 days on Kayaderosseras Creek and 79 days on East Koy Creek. During the creel survey period, we issued 148 and 104 survey cards on the Kayaderosseras and East Koy Creeks respectively. A total of 196 cards were returned from both streams yielding a mean response rate of ~ 0.78. After eliminating interviews that took place when an angler had been fishing for less than 30 minutes and cards that could not be matched with interview data due to angler reporting errors or inaccuracies, we had a total of 167 survey pairs (i.e., angler interview + returned catch card) remaining for analysis, allowing for a calculation of daily catch for 63 angler days.

The mean catch rates differed significantly between the two estimators. The mean catch rate was 0.45 for completed trips using the ratio of means estimator and 0.89 for incomplete trips (Table 2). Mean estimates of catch rate were 44% higher for incomplete trips than for estimates calculated from complete trips, despite truncating data from interviews that took place after less than 30 minutes of angling. Regression analyses between the two estimators revealed that the mean of the ratios estimator did not yield a significant positive bias relative to the ratio of the means estimator at the stream level (PPMCC; $r = 0.30$; $p = 0.14$); however, there was significant positive bias between incomplete and complete trips at the individual level, (PPMCC; $r = 0.63$; $p = 0.005$) indicating that variation in rates calculated from complete and incomplete trips (i.e., measurement error) rather than the estimators was the source of bias for these data. When we compared the mean of ratios to the ratio of means estimates using data from complete trips alone, bias was reduced to 7% and 2% for East Koy and Kayaderosseras Creeks respectively (Table 1). Sampling variances did not differ significantly for any of the comparisons (Levene Test: $w = 0.73$; $p = 0.81$).

Log transformed data had fewer departures from the qline on our qqplot and failed to reject the Shapiro-Wilk test ($w = 0.918$; $p = 0.45$), indicating that log transformation satisfied normality assumptions. Although our data were bivariate normally distributed after log transformation, because our correlation coefficient (r) was significant, standard major axis and ranged major axis regression were the appropriate estimators (Legendre and Legendre 2012). The scatterplot of our data did not indicate the presence of major outliers, thus ranged major axis was the most appropriate method for comparing the estimators and for use as a corrective model. MA, SMA, and OLS estimates are provided only to allow comparison among methods (Figure 1). Analysis from our comparison of OLS model and model II regressions (MA, SMA, and RMA) resulted in different estimates of the slope (Figure 2). As predicted, the OLS model provided the lowest slope estimate, indicating that the slope was biased due to the presence of measurement error in both variables. Without the corrective models, the catch rate estimated from incomplete trips differed from complete trip estimates by 44%. Use of the OLS equation as a bias corrector model (as in Keefe et al. 2009) underestimated catch rates from incomplete trips by 30%when compared to complete trips (Table 2). MA also underestimated catch rates from incomplete trips by 26%when compared to complete trips. The RMA corrective modelperformed best, accounting for approximately 91% of the incomplete trip bias and underestimating the complete trip catch rate by only 9% (Table 2). Conversely, the SMA model overestimated catch rates from incomplete trips by 16% when compared to complete trips.

Conclusion

Our catch card program showed that incomplete fishing trips potentially underestimate angler effort and overestimate catch and harvest statistics.Our linear regression analysis provided a corrective model to help reduce the bias associated with the roving survey design (Figure 1).

While estimates differed substantially when using the mean of ratios for incomplete trips and the ratio of means for complete trips, differences were minimal when using the two estimates on complete trips alone. This finding likely indicates that the estimators themselves are not introducing bias, instead bias is stemming from error in the incomplete trip data collection. Therefore, we recommend that managers continue to use the ratio of means for completed trips and mean of ratios for incomplete trips in addition to discarding interviews where anglers were fishing for less than 30 minutes as recommended in Pollock et al. (1997). However, we recommend coupling roving creel surveys with catch card surveys or other follow-up interview to determine completed trip duration (Jones et al. 1995; Keefe et al. 2009). If bias is found between estimates, we recommend that managers use model II regression when developing species-specific corrective models for catch rates when using roving creels or other sources of incomplete trip data rather than OLS regression.

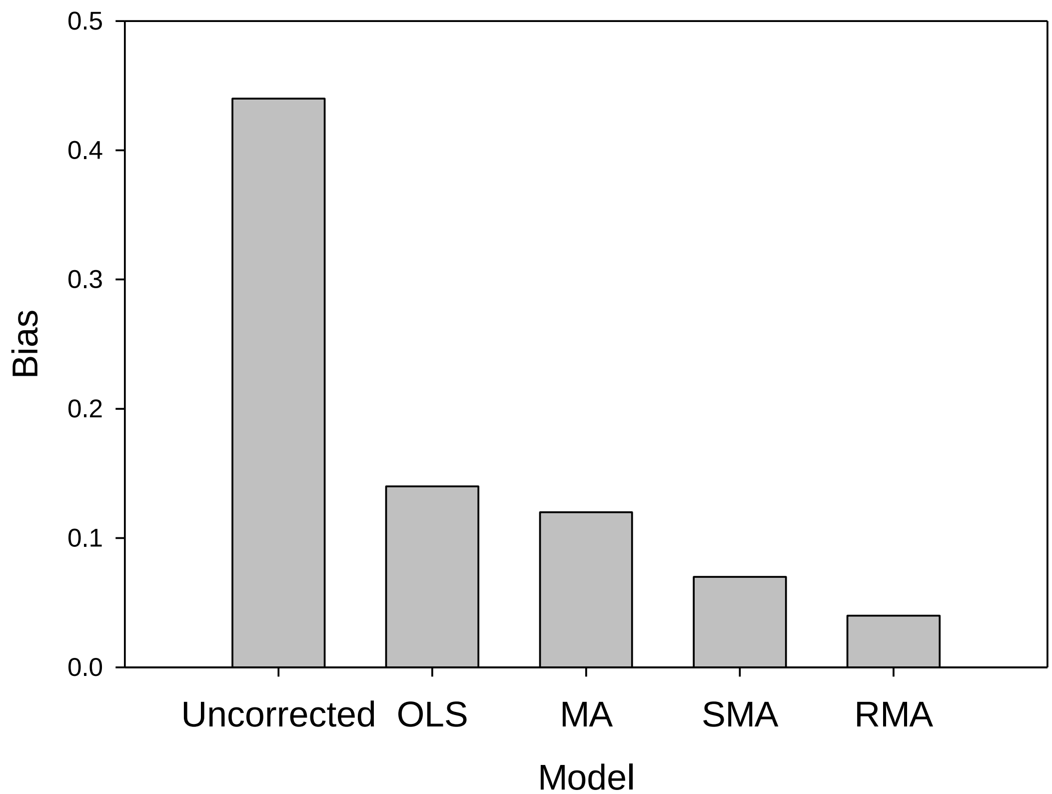


Figure 1. Difference in catch rates estimated using bias corrector models compared to uncorrected estimates. Model 2 regressions (MA, RMA, SMA) performed better than ordinary least squares regression (OLS) and all models performed better than uncorrected estimates.

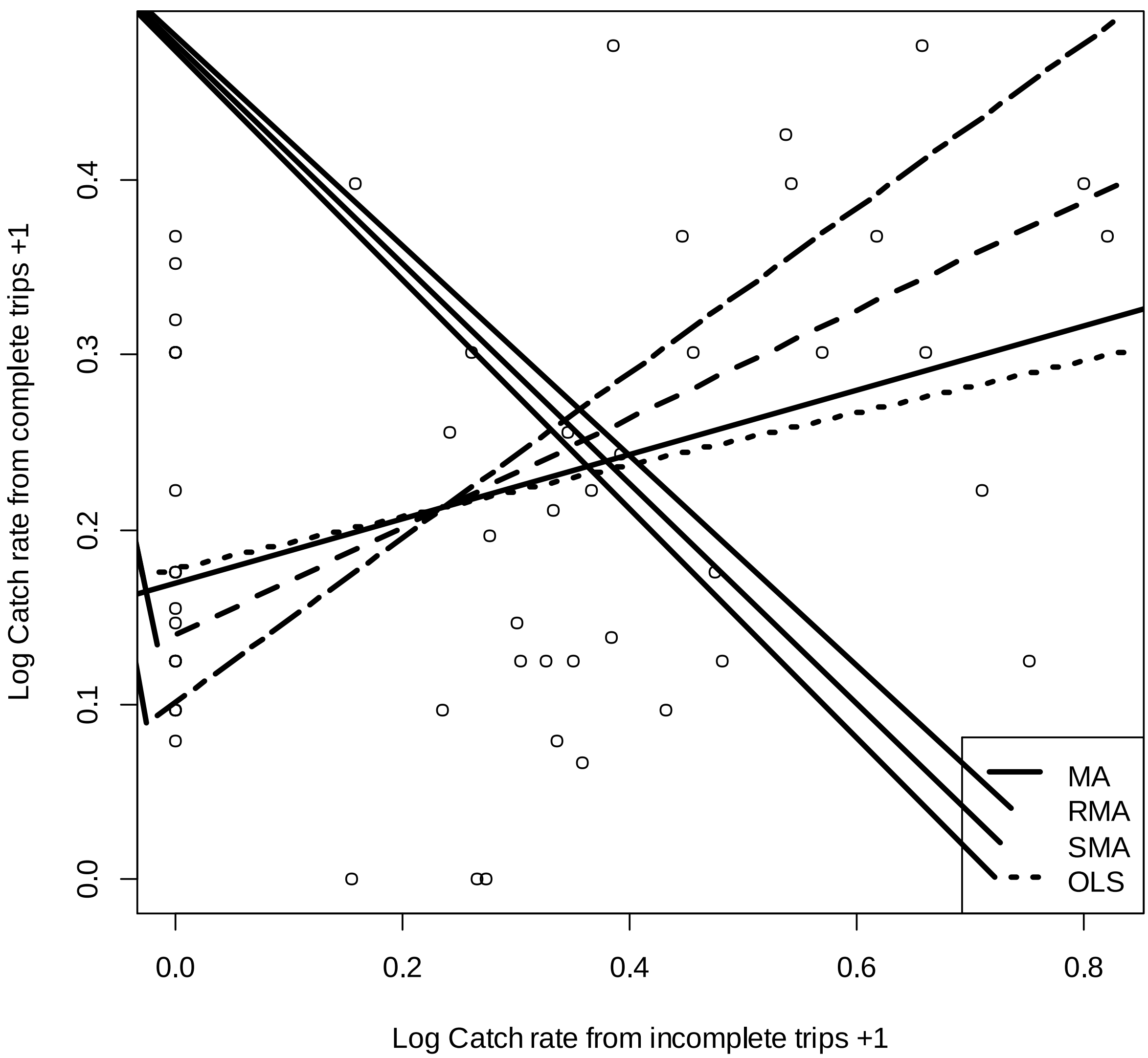


Figure 2. A comparison of mean daily trout catch rates (fish/hour of angling) estimated from incomplete trips using a roving creel survey and complete trips from a mail-in card survey for East Koy and Kayaderosseras Creek. Major axis (MA), ranged major axis (RMA), standard major axis (SMA), and ordinary least squares (OLS) regressions are provided for comparison, though for this dataset, RMA is the most appropriate method. (To improve clarity and interpretation of the figure, note that 1 was added to log transformed values on the x and y axis to keep data in positive quadrant).

Appendix C References

Hoenig, J. M., C. M. Jones, K. H. Pollock, D. S. Robson, and D. L. Wade. 1997. Calculation of catch rate and total catch in roving surveys of anglers. Biometrics :306-317.

Jones, C. M., D. S. Robson, H. D. Lakkis, and J. Kressel . 1995. Properties of catch rates used in analysis of angler surveys. Transactions of the American Fisheries Society. 124(6):911.

Keefe, D. G., R. C. Perry, and J. G. Luther. 2009. A comparison of two methodologies for estimating brook trout catch and harvest rates using incomplete and complete fishing trips. North American Journal of Fisheries Management 29(4):1058-1064.

Legendre, P., and L. Legendre. 2012. Numerical ecology: Third English edition. Elsevier, Amsterdam, The Netherlands.

Pollock, K. H., J. M. Hoenig, C. M. Jones, D. S. Robson, and C. J. Greene. 1997. Catch rate estimation for roving and access point surveys. North American Journal of Fisheries Management 17(1):11-19.

Appendix D. Mini-Creel: Creel survey duration calculator

Ultimately, the cost and logistics required for the adaptive management approach, notably the creel survey component, might prove to be obstacles to implementation in the prevailing management environment. In order to address this potential setback, we conducted a creel survey duration simulation to help managers determine the optimal number of creel days to sample to achieve a given level of certainty. We used a random number generator to select a random subset of data that included just one weekday and one weekend day per month as opposed to the full dataset that included all weekend days and between 8 and 18 weekdays per month. We then calculated CPUE on the subset of data and found that mean CPUE estimates were similar but the 95% confidence intervals were much wider (Figure 1). We then plotted the standard error of the estimates each day for a given creel duration ranging from 60 to 200 days (Figure 2). For visualization, we plotted the standard error needed in order to detect a 10% or 20% change in a given parameter (Figure 2). Finally, we plotted the approximate cost of a creel survey based on its duration an assumed operating cost on the secondary axis (Figure 2). The estimated cost, creel duration range, and percent change can be adjusted in the calculator according to management needs. We believe this tool will enable managers to balance the tradeoffs between cost and uncertainty and potentially reduce the number of creel days used in a given study in many cases, which might allow for the number of creel surveys conducted in a given region to be increased.

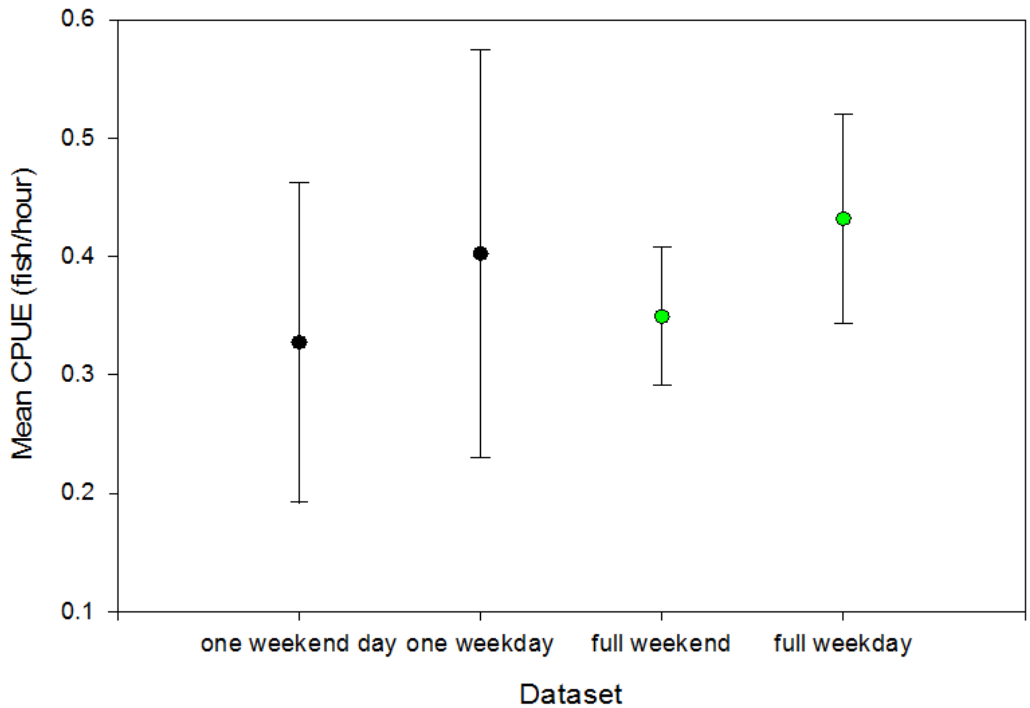


Figure 1. Random number generator to randomly select a subset of data, in black, that includes just one weekday and weekend day per month, while the full dataset, in green, included all weekend days in a month and between 8 and 18 weekdays per month.

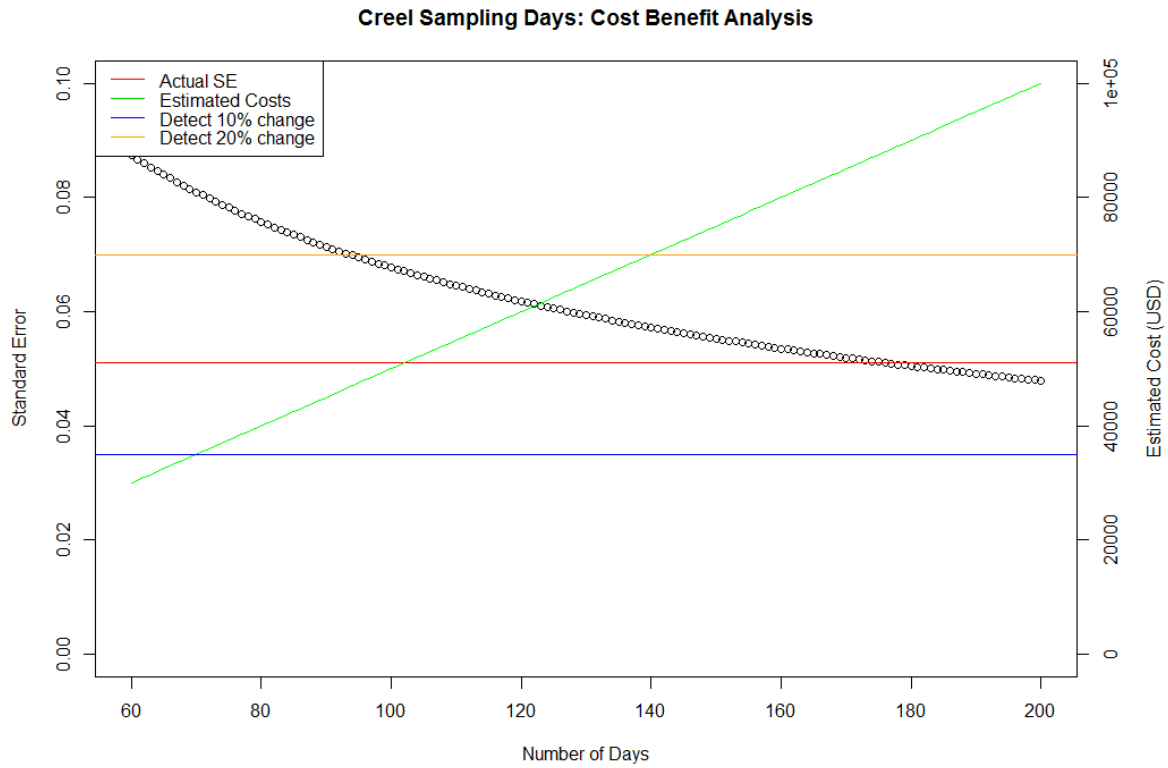


Figure 2. The black dots represent standard error for CPUE plotted as function of the duration of the creel survey. The superimposed red line shows our actual SE for all the streams, while the blue and orange lines show the number of days you would need to sample to be able to detect a 10% change (blue) vs. a 20% change(orange). Estimate of cost at a given survey duration, represented by the green line, which plots the estimated cost for the season (based on an operating cost of $500/day)

Appendix E. Trout2014 worksheet instructions

Trout2014 consists of four separate sheets. User modifiable cells are colored yellow for ease of identification. The first sheet, labeled "Main" lets the user set general parameters such as the year, season dates, and effort for the particular stream. Stocking increments can also be set with release date, density/ac, age, and mean size. Space is available for five increments and unused spaces can simply be set to a population of zero. Population estimates of wild fish derived from electrofishing surveys should also be added here using the option "Wild" under the "Age/Type" menu. One should be able to accomplish a basic analysis of a stream by modifying only the settings on this sheet. To the right of the parameter windows is a box that shows basic statistics about the stream as stocked including season length, predicted mean CPUE, weighted CPUE, and predicted harvest. Finally, the bulk of the sheet is a day-by-day prediction of population densities for each stocked increment, CPUE, harvest, and biomass.

The "Charts" sheet contains charts that provide a visual representation of the data shown on the "Main" sheet. These charts update dynamically and can be copied from Excel to present the relative effects of various stocking strategies. All charts can be modified as needed without affecting the rest of the model.

The "Parameters" sheet allows the user to set values such as creel, growth, and mortality rates as well as the distribution of effort throughout the season. These cells are referred to by the "Main" and "Calculations" sheets so changing them has wide-ranging effects. The "custom" options enable the user to explore the effects of parameter changes without modifying the preset values. Custom settings can also be used to model fish not included in the default model. These could be other species, age classes, or a mix of the two. Given known parameter values this allows for the modeling of more complex fisheries. A "Justification" section is also included on the far right side, which should be completed if non-default parameter values are used. Whenever values are derived from published or gray literature the full citation should be included in this section.

Trout2014 also contains a tab labeled "How to Use". Under this tab there are instructions for running a basic CROTS analysis, as well as general tips and useful information for more advanced analyses.

Finally, the "Calculations" sheet contains the daily values for effort, harvest, natural mortality, and growth. This sheet is not intended to be modified but instead contains the interim stages of the model calculations. Viewing this sheet can be useful to understand how the model is affected by parameter changes and to elucidate the primary drivers of mortality.

Appendix F. Research Team Partners

Cornell University

Alexander Alexiades, Benjamin Marcy Quay, Dr. Patrick Sullivan, Dr. William Fisher, Dr. Clifford Kraft

NYSDEC

Albany: Shaun Keeler, Fred Henson

Region 1: Charles Guthrie

Region 3: Bob Angyal

Region 4: Dan Zielinski

Region 5: Robert Fiorentino

Region 6: Frank Flack, David Erway

Region 7: David Lemon, Scott Prindle

Region 8: Pete Austerman

Region 9: Scott Cornett.

Appendix G. Fishing regulations in effect (2011-2013) on the stream reaches included in this study.

Carmans River:

- Brook Trout, April 1-September 30, catch and release only
- From LIPA transmission lines at Gate G upstream to Yaphank Avenue, Trout, April 1 – September 30, catch and release only, fly fishing only
- From Cement Dam upstream to LIPA transmission lines at Gate G, Brown and Rainbow Trout, April 1 – September 30, 9" minimum, 3/day, fly fishing only

Esopus Creek:

- Trout, April 1 – November 30, any size, 5/day

Kinderhook Creek:

- **Statewide Trout Regulation**[4], April 1 – October 15, any size, 5/day

Kayaderosseras Creek:

- Trout, all year, any size, 5/day

Oriskany Creek:

- Trout, April 1 – October 15, any size, 5/day
- Trout, October 16 – March 31, catch and release only, artificial lures only

Big Creek:

- **Statewide Trout Regulation**, April 1 – October 15, any size, 5/day

Otselic River:

- Trout, April 1 – October 15, any size, 5/day with no more than 2 longer than 12"
- Trout, October 16 – March 31, catch and release only, artificial lures only

Meads Creek:

- Trout, April 1 – October 15, any size, 5/day with no more than 2 longer than 12"

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[4] Except for the most downstream ¼ mile of the study reach (from Adams Crossing/Hanky Mull Hill Road to Wyomannock Creek) where the open season is extended to November 30. Aside from the extended season, all other aspects of the statewide trout regulation applied downstream of Adams Crossing. Therefore, during the April 1 – October 15 creel survey, the regulation on this reach can be considered identical to the rest of the study reach above Adams Crossing.

East Koy Creek:

- Trout, April 1 – October 15, any size, 5/day with no more than 2 longer than 12”
- Trout, October 16 – March 31, catch and release only, artificial lures only