Catch inequality occurs when a small number of anglers catch a disproportionally large number of fish. Catch inequality is a common occurrence in recreational fisheries, but long-term changes in catch inequality are rarely measured. We evaluated catch inequality in archived long-term complete-trip creel census records from a trout stream in southeastern New York. These records document all fish caught for each angler over a 20-year period. Catch inequality, as measured by the Gini coefficient, increased significantly during the study period. Catch per unit effort and an inequality-standardized measure of catch per unit effort declined significantly throughout the study. We tested the hypothesis that between-angler inequality increases as catch per unit effort declines. There was no change in between-angler inequality but between-trip inequality increased substantially. Trip-to-trip variability, not between-angler variability, accounts for increased catch inequality when catch per unit effort declines. Catch inequality increases as catch per unit effort declines, but less successful anglers are not disproportionately affected.
of fishing quality or success and may lead to ineffective management strategies. For instance, Cook et al. (2001) suggested that bag limits in Minnesota were ineffective and misleading benchmarks of angling success because catch inequality results in few anglers catching enough fish to reach these limits.

Previous theoretical and empirical work has shown that catch inequality is closely related to catch per unit effort (Smith 1990; Baccante 1995). Thompson (1976) proved that, in theory, approximately 90% of fish could be caught by 10% of anglers owing to chance alone. The magnitude of inequality in his analysis was determined by a Poisson distribution assuming equal effort for all the anglers and equal catchability of the fish. If the mean catch is low, the distribution of catches from the Poisson model will be highly skewed and highly unequal. If the mean catch is high, the Poisson distribution of catches is less skewed and has lower inequality (Seekell 2011). Thompson’s Poisson model was not supported empirically, probably because anglers contributed varying amounts of effort to the fishery (Thompson 1976; Seekell 2011). Smith (1990) noted that most catch distributions exhibit a lognormal distribution, not a Poisson distribution, and suggested that this pattern results from a multiplicative function of innate differences between anglers. Details of the origin of lognormal distributions from multiplicative processes are given by Mitzenmacher (2004) and Limpert et al. (2001). Seekell (2011) noted that effort has a lognormal distribution and found that catch distributions were not significantly different from Thompson’s random catch model when effort was introduced into the Poisson process as a random lognormal variable. This model produces discrete lognormally distributed catches, consistent with the observations of Smith (1990). In this case, catch per unit effort still plays a critical role in determining the magnitude of catch inequality. Empirically, Baccante (1995) found that catches of walleye Sander vitreus in 31 fisheries were highly unequal and that this inequality was strongly correlated to catch per unit effort. A high catch per unit effort corresponded to low inequality and a low catch per unit effort corresponded to high inequality. This pattern was attributed to the effects of resource scarcity, which could produce skewed catch distributions when few anglers catch fish (Smith 1990; Baccante 1995).

Catch inequality is rarely recorded over long-term studies and little is known about the variability or drivers of inequality. Mosindy and Duffy (2007) found that inequality in the catches and sightings of muskellunge Esox masquinongy recorded in angler diaries at Lake of the Woods, Ontario declined over five periods from 1988 to 2005. Catch and sightings per unit effort increased during this period. Van Poorten and Post (2005) found that inequality in the catch of rainbow trout Oncorhynchus mykiss increased over a fishing season at Cabin Lake, Alberta. This increased inequality coincided with decreasing catch per unit effort (van Poorten and Post 2005). These results, with those of Baccante (1995), provide strong empirical evidence for an inverse relationship between catch per unit effort and both spatial and temporal catch inequality.

Smith (1990) suggested that inequality increases with declining catch per unit effort and less successful anglers are disproportionately affected when catch per unit effort declines because of resource scarcity or harvest limitations. Thus, between-angler catch inequality should increase as catch per unit effort declines. This hypothesis has not yet been rigorously tested for recreational fisheries. In this study, we analyzed long-term creel census data for brown trout Salmo trutta in a delimited section of Wappinger Creek near Millbrook, New York. We tested for trends in catch per unit effort and inequality. We decomposed inequality into differences in success between anglers and differences in success between trips. We test Smith’s (1990) resource scarcity hypothesis by comparing long-term changes in inequality and catch per unit effort.

METHODS

Sampling methodology.—We retrieved archived catch and effort (h) data (1988–2007) from angler logs (n = 1499) for the brown trout fishery in the East Branch of Wappinger Creek where it flows through the Cary Institute of Ecosystem Studies (IES), Millbrook, New York (41.785823°N, 73.741447°W). All anglers were required to participate in the angler-log program as a condition of receiving a fishing permit from IES. As a result, the IES angler-log data represent a complete census of anglers and are not subject to the avidity biases typically associated with soliciting a sample of volunteer participants (Cooke et al. 2000). All new participants were required to attend an orientation session with the program manager for instruction on data recording. Instructions were provided on each angler-log sheet and anglers were required to submit log sheets after each trip. Anglers were explicitly instructed to record all trips, even if no fish were caught. We believe that recording bias (not recording trips during which no fish were caught) was minimal because there were an abundance of records with zero fish caught, even for anglers with very high season-average catch per unit effort. We only used records with a party size of one because party size is known to be inversely related to angler success (VanDe Valk et al. 2007). This eliminates party size as a potential confounding factor in our analysis. Only 12% (n = 180) of trips included more than one angler.

Statistical analysis.—Catch inequality is generally evaluated by plotting Lorenz curves (e.g., Baccante 1995; Mosindy and Duffy 2007). A Lorenz curve is a plot of the cumulative proportion of fish caught by the cumulative proportion of effort. The Lorenz curve is a diagonal if there is complete catch equality (10% of fish are caught with 10% of effort, 20% of fish are caught with 20% of effort, and so on). The Lorenz curve is concave if there is catch inequality (e.g., 90% of fish are caught with 10% of effort). The Lorenz curve can be plotted to evaluate inequality between anglers or between trips (Lambert and Aronson 1993). Between-angler inequality is evaluated by plotting the cumulative proportion of catch by the cumulative proportion of effort for each angler’s contribution to the
season total. Between-trip inequality is evaluated by plotting the cumulative proportion of catch by the cumulative proportion of effort that each trip contributes to the season total. Figure 1 is an example of these two curves from the 2001 fishing season. The between-trip Lorenz curve is always as concave or more concave than the between-angler curve (between-trip data are always as or more unequal than between-angler data) because there is inequality within, and overlap between, the trip-to-trip success of each angler (Lambert and Aronson 1993; Yao 1999).

The Lorenz curve is described numerically by the Gini coefficient (Baccante 1995; Yao 1999). The Gini coefficient is equal to two times the area between the Lorenz curve and a diagonal line of equality. A Gini coefficient of 0 indicates complete equality. A Gini coefficient of 1 indicates perfect inequality. The Gini coefficient is equivalent to a standardized version of the Gini mean difference statistic (Jasso 1979). The mean difference statistic is the expected difference in catch between two anglers as a proportion of the mean catch (Jasso 1979). A high Gini coefficient is consistent with large variability between measurements and a low Gini coefficient is representative of low variability between measurements.

We calculated Gini coefficients using the unbiased formulation of Yao (1999) as follows:

\[
G = 1 - \sum_{i=1}^{n} p_i \left( 2 \sum_{k=1}^{i} Q_i - w_i \right) \text{ where } Q_i = \sum_{k=1}^{i} w_i, \tag{1}
\]

where \(G\) is the Gini coefficient, \(w_i\) and \(p_i\) are the relative share of annual catch and effort, respectively, and each sums to unity, when the data are strictly in ascending order of catch per unit effort (Yao 1999). We calculated Gini coefficients for the between-trip inequality and between-angler inequality Lorenz curves for each year.

We calculated catch per unit effort for each year from the catch for each trip weighted by the proportion of total fishing time that each trip accounted for during the season as follows:

\[
CPUE = \frac{\sum_{i=1}^{N} w_i y_i}{\sum_{i=1}^{N} w_i x_i} \tag{2}
\]

where \(CPUE\) is the catch per unit effort, \(w_i\) is the proportion of total fishing time accounted for by trip \(i\) during the calculation year, \(y_i\) is the number of fish caught on trip \(i\), and \(x_i\) is the effort (angling hours) of trip \(i\). This formulation provides unbiased catch rate estimates but is not generally applied to fisheries data because the weights are unknown (Jones et al. 1995). However, this formula is appropriate for our study because the data comprise a complete census and the values of the weights are known exactly (Jones et al. 1995).

The effective catch per unit effort is a function of mean catch per unit effort and inequality. Catch-per-unit-effort estimates can be standardized by inequality to better compare the quality of the fishery between years by taking into account both mean catch and the spread of the distribution of catches. We adjusted catch per unit effort for each year by calculating the Sheshinski-Sen-Yitzhaki index (SSY), which balances inequality and mean catch rate (Bishop et al. 1991), as follows:

\[
SSY = CPUE(1 - G), \tag{3}
\]

where \(CPUE\) is the catch per unit effort and \(G\) is the between-trip Gini coefficient for the year. This provides the equivalent of a mean “standard of living” for catch rate (Bishop et al. 1991). The adjustment for inequality could be altered by adding weights to the catch per unit effort and Gini coefficient, but it is unclear what an appropriate weighting would be (Bishop et al. 1991). The catch per unit effort and SSY represent the opposite extremes of no adjustment and full adjustment for inequality. Hence, consistent results between these metrics remove the need to select weights because any weight will lead to the same conclusion.

We also calculated the mean trip length (\(h\)), trip length variance, number of trips per season, and total effort (hours per season). We calculated the Pearson’s product-moment correlation coefficient between these variables, the Gini coefficient, and year as the basic test for trend. We controlled for confounding trends by calculating partial correlation coefficients between these variables and the Gini coefficients. This reduces the chance of identifying a spurious correlation between two variables. Statistical tests were evaluated at the \(\alpha = 0.05\) level of significance. We plotted Gini coefficients from this study and those from 27 walleye fisheries (Baccante 1995) and a rainbow trout fishery (van Poorten and Post 2005) by catch per unit effort.
FIGURE 2. Catch per unit effort (CPUE) declined significantly during the study ($r = -0.637, P = 0.003$). Inequality-adjusted catch per unit effort (SSY) also declined significantly during the study ($r = -0.685, P < 0.010$). Ordinary least-squares regression lines were plotted to emphasize the trends.

to evaluate the relationship between the two over a wider range of catch rates (0.009–3.740 fish/h).

RESULTS AND DISCUSSION

The recreational fishing quality of the East Branch of Wappinger Creek trout fishery declined during the 20-year study period. The decline is characterized by a significantly reduced catch per unit effort and SSY (Figure 2). This indicates that the fishing quality for individual anglers declined over the study period regardless of the weight put on catch inequality. Consistent with this decline, overall inequality increased significantly during the study period (Figure 3). These values, calculated by trip-level data, indicate an increase in trip-to-trip variability in catch over time. However, there was no significant change in between-angler inequality (Figure 3). Thus increasing variability during the period of declining catch per unit effort is because of increasing trip-to-trip variability and not increased variability between anglers. Total effort, total number of trips, mean trip length, and trip length variance declined significantly (Table 1). These variables, with the exception of trip length variance, were inversely and significantly correlated with the Gini coefficient.

When the partial correlation coefficient was calculated to account for the confounding trends of individual variables only catch per unit effort was significantly related to the Gini coefficient ($r = -0.537, P = 0.018$) (Table 1). This increase in between-trip Gini coefficient with declining catch per unit effort is consistent with theoretical expectations and previous empirical results (e.g., Baccante 1995; Mosindy and Duffy 2007). The relationship between Gini coefficients and catch per unit effort was strong, but nonlinear, when we plotted our data with literature data from walleye and rainbow trout fisheries (Figure 4). This provides robust evidence for a strong relationship between the catch inequality and catch per unit effort over a wide range of catch rates and between several fisheries.

TABLE 1. Pearson correlation coefficients for year, between-trip Gini coefficient, catch per unit effort (fish per hour) per season, total effort (h) per season, total number of trips per season, mean trip length (h) per season, and trip length variance per season. Probability values are in parentheses. Significant correlations with year represent trends over time. Every variable has a significant linear trend during the study period. Partial correlation coefficients remove spurious relationships by controlling for these linear trends.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Correlation coefficient</th>
<th>Partial correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year</td>
<td>Gini coefficient</td>
</tr>
<tr>
<td>Between-trip Gini coefficient</td>
<td>$0.656 (0.002)$</td>
<td>$-0.730 (&lt;0.001)$</td>
</tr>
<tr>
<td>Catch per unit effort</td>
<td>$-0.637 (0.003)$</td>
<td>$-0.672 (0.001)$</td>
</tr>
<tr>
<td>Total effort</td>
<td>$-0.726 (&lt;0.001)$</td>
<td>$-0.490 (0.028)$</td>
</tr>
<tr>
<td>Total trips</td>
<td>$-0.527 (0.017)$</td>
<td>$-0.694 (0.001)$</td>
</tr>
<tr>
<td>Mean trip length</td>
<td>$-0.784 (&lt;0.001)$</td>
<td>$0.229 (0.330)$</td>
</tr>
<tr>
<td>Trip length variance</td>
<td>$-0.574 (0.008)$</td>
<td></td>
</tr>
</tbody>
</table>
The main result of this analysis is that trip-to-trip inequality increases with declining catch per unit effort, but between-angler inequality does not change. Our analysis does not support the hypothesis that less successful anglers are disproportionately affected by declining catch per unit effort because we found no long-term change in between-angler inequality. Our analysis does not identify the cause of long-term decline in catch per unit effort. We have no independent population estimates for this stream to identify changes in population size or catchability as the cause of declining catch per unit effort. However, the causal mechanism is not necessary for the change-in-inequality perspective taken in this work because anglers are principally concerned with catching fish and not the factors that determine success (Cook et al. 2001). Qualitatively, droughts have likely reduced fish abundance in recent years by increasing water temperature. Low water levels are believed to have trapped brown trout in small pools leading to increased predation from herons and river otters. Recent beaver activity and a major log-jam may have further altered the natural variability in discharge leading to a loss of distinct habitat types that are critical to brown trout.

To our knowledge, differences in between-angler and between-trip catch inequality have not been previously described for recreational fisheries. Hence, there is little mechanistic or theoretical basis for interpreting the inconsistent trends in between-angler and between-trip inequality. Several analyses have measured the effects of skill in commercial fisheries based on panel data through the economic framework of technical efficiency and production frontier analysis (e.g., Kirkley et al. 1998; Squires and Kirkley 1999; Alvarez and Schmidt 2006). These studies have found innate differences between commercial boat captains that explain variability in success, but differences also include strong influences of environmental stochasticity (Kirkley et al. 1998; Squires and Kirkley 1999).

Alvarez and Schmidt (2006) found that the skill signals in commercial fisheries are visible at aggregated temporal scales while trip-to-trip differences in success also represent environmental stochasticity. Our results of between-angler and between-trip measures of inequality are analogous to the skill and stochasticity signals identified by these authors. Between-angler Gini coefficients integrate entire fishing seasons. The long-term nature of these coefficients probably describes the innate differences in angler ability. The short-term nature of the between-trip Gini coefficient is likely descriptive of the effects of environmental stochasticity and explains why, on any given trip, a weak angler can be more successful than a skilled angler. Thus the increasing trip-to-trip variability represents increasing environmental stochasticity while the constant between-angler variability reflects little or no change in the skill of the angling population.

Changing catch per unit effort can be attributed to shifts in the fish population or the skill of the angling population. A shift to a more skilled angling population could confound monitoring and management efforts by making catch-per-unit-effort estimates hyperstable to changes in the abundance or catchability of fish. Conversely, a shift to a less skilled angling population could depress catch-per-unit-effort estimates with no change in fish population, giving the false appearance of a declining fishery. The lack of change in between-angler inequality demonstrates that changes in catch per unit effort are because of large scale changes in the fish population and not changes in the skill level of the angling population. Thus catch-per-unit-effort estimates derived from long-term, complete-trip angler logs provide good, low-cost indications of changes in recreational fishing quality.

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REFERENCES


