Can Management Reduce Harvest Inequality in Recreational Fisheries?

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Abstract
Harvest inequality, a situation in which most of the fish are harvested by a disproportionately small number of anglers, is a characteristic of most recreational fisheries. Harvest inequality develops when a few anglers harvest a very large number of fish or when many anglers harvest few fish. Identifying the cause of harvest inequality is critical to understanding the potential for management to reduce the inequality. Management efforts aimed at reducing the top anglers’ take will have only a modest impact if the harvest inequality is actually caused by many anglers harvesting no fish. We measured harvest inequality in 20 years of creel census data from a trout stream in southeastern New York. We calculated Lorenz curve asymmetry coefficients (S) to test whether harvest inequality was attributable to small harvests by many anglers or large harvests by a few anglers. Harvest inequality in the fishery was consistently high and the S-value was always less than 1.0, indicating that harvest inequality was caused by many anglers harvesting no fish rather than by few anglers harvesting many fish. This influence becomes stronger with increased harvest. We conclude that management is unlikely to influence the magnitudes of harvest inequality in recreational fisheries because regulations do not target the principal cause of harvest inequality.

Angler satisfaction with fisheries is related to the evenness of the distribution of catch among anglers (cf. Hudgins and Davies 1984). However, the distribution of catch is heavily influenced by angler effort, which is difficult to regulate (Hilborn 1985; Radomski 2003; Sullivan 2003; Seekell 2011). Harvest is more manageable than catch, and consequently a principal focus of recreational fisheries management has been to promote a relatively equal distribution of harvest with the goal of improving angler satisfaction with fisheries (cf. Hudgins and Davies 1984; Cook et al. 2001; Radomski 2003; Paukert et al. 2007). However, a fundamental understanding of the patterns and dynamics of harvest inequality is lacking, and the efficacy of management in influencing harvest inequality is unknown (Cook et al. 2001; Radomski et al. 2001; Paukert et al. 2007).

Harvest inequality occurs when most of the fish are harvested by a disproportionately small number of anglers (Cook et al. 2001). Knowing the cause of harvest inequality is critical to understanding the potential effects of management because most harvest regulations only influence the top harvesters. Harvest inequality develops if a few anglers take a large number of fish relative to the average harvest (Cook et al. 2001). However, harvest inequality can also develop if many anglers take no fish. The few anglers that do take fish then appear to harvest a disproportionately large number of fish, even if their harvest consists of only a few fish (i.e., the harvest is below a creel limit). This distinction in the cause of harvest inequality is important because creel limits (or reduced creel limits) are often implemented to reduce harvest inequality (see Cook et al. 2001; Radomski et al. 2001; Radomski 2003; Paukert et al. 2007), but the limits will have only a modest impact in reducing harvest inequality if it is caused by a situation of many anglers harvesting no fish.

Reports of the magnitude of harvest inequality are rare. Cook et al. (2001) measured harvest inequality in Minnesota lakes by
using complete-trip creel surveys. Those authors found that the magnitude of harvest inequality varied between six commonly targeted species, but all of the species were characterized by an abundance of anglers with no harvest. This result is likely attributable to the fact that harvest is not the principal motivation of all recreational freshwater anglers, and many anglers strictly participate in voluntary catch-and-release fishing (e.g., Chipman and Helfrich 1988; Sutton 2003; Schramm and Gerard 2004; Arlinghaus 2006). The results of Cook et al. (2001) suggest that harvest inequality is due to low harvest by many anglers rather than to large harvest by a few anglers. However, there has not been a rigorous test to discriminate between the two potential causes of harvest inequality. In this study, we analyzed long-term creel census data for Brown Trout *Salmo trutta* from a delimited section of Wappinger Creek near Millbrook, New York. We applied statistical measures of inequality to test whether small harvests by many anglers or large harvests by a few anglers were causing harvest inequality; our goal was to infer the potential efficacy of management in influencing the magnitude of harvest inequality.

**METHODS**

*Data.*—We retrieved angler logs \((n = 1,499)\) archived by the Cary Institute of Ecosystem Studies (hereafter, Cary Institute) from 1988 to 2007 for the Brown Trout fishery in the East Branch of Wappinger Creek where the creek flows through the Cary Institute’s property \((41°47′8.9628″\text{N, }73°44′29.2086″\text{W}).\) Seekell et al. (2011a) provided a detailed description of the survey methodology. Briefly, these data represent a complete census of recreational fishing in this fishery. All anglers recorded effort \((h)\), catch, harvest, and party size for each trip as a condition of receiving a fishing permit from the Cary Institute. Records were submitted after each trip. We used records with a party size of one angler to minimize potential confounding factors associated with variable group sizes (Seekell et al. 2011a). We believe that the potential for confounding variability from substitutability or targeting of different species in influencing catching power or harvesting decisions was minimal because 99% of the fish caught were Brown Trout (Cook et al. 2001; Arlinghaus et al. 2007).

*Statistical analysis.*—Harvest inequality was visualized by plotting Lorenz curves and was quantified by calculating Gini coefficients (Smith 1990; Baccante 1995; Cook et al. 2001). These methods are described in detail by Seekell et al. (2011a). Briefly, Lorenz curves and Gini coefficients assess the relationship between the cumulative proportion of fish harvested and the cumulative proportion of effort. If there is harvest inequality, Lorenz curves become more concave and Gini coefficients increase from 0 to near 1.0. We calculated Gini coefficients for each year according to the method of Damgaard and Weiner (2000).

The Gini coefficient is 2 times the area between the Lorenz curve and a hypothetical curve describing a scenario in which anglers harvest an equal proportion of fish. A consequence of this methodology is that differently shaped harvest distributions can display the same level of inequality (i.e., they can have the same Gini coefficient value). For example, the dashed black and gray Lorenz curves in Figure 1 represent distributions of harvest with the same level of inequality. However, the distributions are different because one is dominated by a large number of anglers that harvest few fish (the gray dashed Lorenz curve, describing a distribution in which about 50% of the anglers harvest about 10% of the fish), whereas the other is dominated by a few anglers that harvest large numbers of fish (the black dashed Lorenz curve, describing a distribution in which about 50% of the anglers harvest about 50% of the fish). Hence, the shape of the Lorenz curve can be used to infer whether harvest inequality is caused by (1) few anglers harvesting a relatively large number of fish (relative to the mean harvest) or (2) many anglers harvesting a small number of fish (cf. Chen et al. 2010). To quantify these different Lorenz curve shapes, we calculated the Lorenz curve asymmetry coefficient \((S; \text{Damgaard and Weiner 2000}). An S less than 1.0 describes a Lorenz curve in which the point with a slope equal to 1.0 is below the axis of symmetry (solid gray diagonal line in Figure 1), indicating low harvest inequality.

![Hypothetical Lorenz curves](image)

*FIGURE 1.* Hypothetical Lorenz curves (modified from Damgaard and Weiner 2000 and Seekell et al. 2011b). The dark-gray bold line is the line of equality (e.g., 10% of fishing effort results in 10% of harvest, 30% of effort results in 30% of harvest, and so on). The light-gray solid line is the axis of symmetry. The black and gray dashed lines are Lorenz curves representing the same amount of inequality (same Gini coefficient) but with different shapes described by the asymmetry coefficient \(S\) (i.e., \(S < 1.0\) for the gray dashed curve; \(S > 1.0\) for the black dashed curve). When \(S\) is less than 1.0, the distribution of harvest is dominated by a large number of anglers that harvest few or no fish. When \(S\) is greater than 1.0, the distribution of harvest is dominated by a few anglers that harvest a very large number of fish (cf. Chen et al. 2010). The black Lorenz curve (solid curve) has greater inequality (larger Gini coefficient) than the dashed curves, but it is symmetrical \((S = 1.0)\).
Harvest inequality in the Wappinger Creek Brown Trout fishery was extreme (mean Gini coefficient = 0.85; SD = 0.08; range = 0.68–0.95). The harvest Gini coefficients were considerably greater than the values reported by Seekell et al. (2011a) for catch distributions in this fishery (mean Gini coefficient = 0.51; SD = 0.07; range = 0.43–0.71). This result means that there is nothing inherent in the process of catching fish that causes extreme harvest inequality—rather, the extreme inequality develops from the decisions made by anglers after the fish are caught. The harvest Lorenz curve displays a large number of zero-harvest trips relative to the number of trips with zero catch, whereas the curves are close to each other at the upper ends of their distributions (Figure 2). This suggests that the greater harvest inequality relative to catch inequality is due to the abundance of nonharvesting anglers rather than to large harvests by a few anglers. In the interest of brevity, we do not present figures for all 20 years, but the shapes of the catch and harvest Lorenz curves in Figure 2 are representative of all catch and harvest curves from the Wappinger Creek data set. Furthermore, the Lorenz curves in Figure 2 are also very similar to Lorenz curves that have been reported for other fisheries. The symmetrical catch Lorenz curve in Figure 2 is similar in shape and magnitude to the catch Lorenz curves presented by Seekell (2011) and Mosindy and Duffy (2007) for other fisheries. The harvest Lorenz curve in Figure 2 is similar in shape and magnitude to harvest Lorenz curves presented by Cook et al. (2001) for six species in Minnesota lakes. These similarities suggest that the patterns identified in our analysis can be generalized to other inland recreational fisheries.

Results and Discussion

Harvest inequality and S-values increased significantly during the study period (Gini coefficient: \( r = 0.613, P < 0.001 \); S-value: \( r = 0.689, P < 0.001 \)). The Gini coefficients and S-values were strongly correlated after we controlled for potentially confounding trends (partial \( r = 0.916, P < 0.001 \)). The positive correlation indicates that the distribution of harvest becomes more unequal as the number of nonharvesting anglers increases (Figure 3). This is because when many anglers do not harvest fish, the point where the cumulative proportion of harvest becomes greater than zero moves closer to the axis of symmetry (Figure 3). This increases the value of S but also increases the Gini coefficient by moving the Lorenz curve near the point furthest from the line of equality (Figure 3). For instance, the insets in Figure 3 show harvest Lorenz curves for 2 years (1988 and 2007) with different levels of inequality (Gini coefficients = 0.65 and 0.81, respectively). The increased inequality in 2007 (the black shaded area between the line of equality and the Lorenz curve) relative to 1988 is due to a greater relative abundance of zero harvests. The S increases because there are so many zero-harvest trips with increased inequality that the point where the Lorenz curve departs from zero harvest is very close to the axis of symmetry. However, the S is always less than 1.0 (mean = 0.82; SD = 0.1; range = 0.60–0.94), indicating that harvest inequality is always caused by an abundance of nonharvesting anglers.

The mean harvest per trip declined during the study (\( r = -0.71, P < 0.001 \)). This decline caused the S and the Gini coefficient to increase because these values are both inversely related to mean harvest per trip (S-value: partial \( r = -0.924, P < 0.001 \); Gini coefficient: partial \( r = -0.756, P < 0.001 \); Figure 4). This result indicates that higher harvest is associated with decreased inequality as well as an increased influence of
nonharvesting anglers in creating the inequality. Hence, as the harvest increases, the harvest inequality in these fisheries will become difficult or impossible to manage through restrictions aimed at harvest-oriented anglers.

Creel limits are usually implemented in part to reduce harvest inequality (Cook et al. 2001; Paukert et al. 2007). However, these limits are generally arbitrary and affect only a few anglers because few anglers harvest the limit (Cook et al. 2001). Creel limits may be ineffective for transferring harvest from top harvesters to nonharvesting anglers because many anglers strictly participate in catch-and-release angling and are unlikely to change their motivation based on regulations aimed at harvest-oriented anglers (Beardmore et al. 2011). When we recalculated Gini coefficients and Lorenz curve $S$-values while excluding anglers that strictly participated in voluntary catch-and-release fishing, the Gini coefficients were slightly lower (by 0.1 on average), indicating less inequality (mean = 0.75; SD = 0.1; range = 0.54–0.88) among harvesting anglers relative to the total population of anglers. However, the values of $S$ also decreased (by 0.08 on average), indicating that harvest inequality was still caused by an abundance of trips with little or no harvest (mean = 0.74; SD = 0.14; range = 0.44–1.03). There was one exception to this: the $S$-value for 1988 was 1.03, indicating that the contribution to inequality was approximately equal between anglers harvesting no fish and those harvesting many fish.

**MANAGEMENT IMPLICATIONS**

Although it is a common characteristic of recreational freshwater fisheries, harvest inequality is likely unmanageable. Harvest inequality is caused by many anglers harvesting no fish rather than by few anglers harvesting many fish. We suggest that minimization of harvest inequality should not be a primary goal of management because harvest inequality does not conflict with the motivations of recreational anglers and, at least in this fishery, it is not caused by a few anglers obtaining large harvests.

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