North American Journal of Fisheries Management 42:815–827, 2022

ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1002/nafm.10778

FEATURE ARTICLE

Paradigm Shift: Applying Capture–Recapture Techniques to Electronic Licensing System Data to Estimate Chinook Salmon Harvest

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Abstract
Implementing creel surveys that produce robust and unbiased estimates of harvest can be complicated, expensive, and labor intensive. Additionally, field personnel often face safety risks associated with traversing roads and highways, occasionally under inclement travel conditions. Here, we develop an alternative method to estimate recreational fish harvest using a hybrid creel that employs capture–recapture techniques in conjunction with data collected from the Oregon Department of Fish and Wildlife's electronic licensing system. We evaluated the method by comparing harvest estimates between the new approach (e-creel) and estimates from a traditional roving creel conducted on four of Oregon's coastal Chinook Salmon *Oncorhynchus tshawytscha* populations in 2019. Our results indicated that Chinook Salmon harvest estimates derived from our hybrid creel approach were more precise than estimates using traditional creel methods. Both methods generated statistically equivalent estimates of Chinook Salmon recreational harvest, differing by only 3.4%. Estimated mean harvest was 1,264 Chinook Salmon based on the e-creel approach versus 1,258 based on the traditional creel approach. On average, the e-creel estimates reduced the SE by 41% relative to traditional creel estimates. Post hoc assessment of spending associated with creel projects in 2019 suggested that a total savings of US$74,525 in personnel and operational cost, corresponding to an average 15% budget reduction per investigation, could be realized by transitioning from a traditional creel design to an e-creel design.

Fishery managers rely on estimates of recreational angler harvest to inform management decisions, such as determining compliance with conservation plans, determining daily and seasonal bag limits for freshwater harvest, guiding negotiations with other regional resource managers, evaluating success, and meeting legal obligations negotiated within international treaties. Typically, the data used to derive recreational harvest estimates are obtained from creel surveys, which are designed to assess angler effort and harvest rates. Generally, creel surveys are considered the "gold" standard because estimates are generated from established techniques that have been proven to produce relatively precise and unbiased harvest estimates (Pollock et al. 1994; Bernard et al. 1998).

Despite being the gold standard, traditional creel surveys have many limitations that can reduce their utility, including complexities in implementing statistically rigorous designs and the financial burdens of administering them. Estimates can be biased by the sampling design when the wrong sampling units are used to generate harvest estimates or if the data inherently contain bias generated during the interview process. For example,

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Received January 20, 2022; accepted April 11, 2022

traditional, on-site creel surveys can be biased by angler avidity (i.e., the disproportionate success of a particular angler) when anglers as opposed to trips are used as the sampling unit within the study design (Thomson 1991). Creel survey data may also misrepresent the fishery when the probability of obtaining an angler interview is related to harvest rate (i.e., length-of-stay bias; Pollock et al. 1994). In this case, the successful anglers are less likely to be intercepted in a roving creel survey because they generally spend less time fishing, especially when there is a one-fish daily bag limit, thus creating a negative bias in the harvest rate. While alternative designs such as access-based creel surveys may be more likely to reduce this type of bias, they are not feasible (cost prohibitive) over large geographic areas with dispersed fishing. Determining an appropriate creel design relies on understanding these complexities and is paramount to implementing a valid program to monitor harvest. Moreover, even when appropriate sampling designs are used, data quality may still suffer, variance may increase, and confidence may diminish. For example, anglers may bias data if they respond untruthfully, such as if they believe their answers may create future fishing restrictions, increase the popularity of a site, or impact other management decisions (Fisher 1996). Even when anglers do not intend to be dishonest, their answers often contain recall bias (i.e., failure to remember their fishing experience accurately; Zarauz et al. 2015), which can be exemplified by anglers showing a propensity to embellish their successes and use rounded numbers to describe their effort (i.e., fishing for 1 h versus 23 min), which can directly affect creel estimates (prestige and digit bias; McCormick et al. 2013). Many of these biases are difficult to identify without supplemental information and have led to many situationally specific creel designs that can be difficult to navigate and implement appropriately. Roving creel designs that require independent interview and effort data may require exceptional care because they rely on terms of effort for both data sets that are assumed to be representative of the fishery. Aside from these data complexities, traditional creel surveys as a management tool are also limited by cost (Vølstad et al. 2006). Expenses related to labor cost, travel resources, and safety measures can create financial burdens (Hansen and Van Kirk 2018), which are often compounded by dwindling state and federal budgets. Consequently, finding new, affordable tools (Gutowsky et al. 2013) and data sources to derive bias-free harvest estimates is critical to effectively manage fisheries.

A relatively new data source that is being explored as an alternative tool for estimating harvest is electronically reported harvest data. Several state agencies have begun to provide electronic licensing options to anglers, and some states are offering electronic options to replace the special validation tags used to report harvest for select species managed under harvest limits. In most cases, electronic licenses and harvest card validation are associated with a smartphone application that automatically transmits retention records back to a management database. The data transmitted can be accessed and may have the potential, in part, to replace some of the information that was traditionally collected through creel surveys.

Electronic licensing systems (ELSs) that provide options for angler self-reporting can be used with auxiliary data sets to generate harvest estimates. For example, data collected from smartphone applications have been combined with field interviews to provide estimates of harvest using capture–recapture techniques (NOAA 2019). Moreover, simulated data suggest that self-reported harvest data can enhance the ability to manage fisheries by providing real-time, nonbiased estimates of recreational harvest when supplemented with on-site surveys (McCormick 2017). This was corroborated by a study comparing angler effort and records in 497 popular fishing lakes in and around Alberta, Canada (Papenfuss et al. 2015). Among the 497 lakes, angler-reported data from a voluntary smartphone application produced estimates of site popularity that were comparable to those from auxiliary data at both regional and seasonal scales (i.e., $r = 0.99$, as reported by Papenfuss et al. 2015). Effort estimates were less reliable using these platforms when the same study examined 36 of the most popular lakes in Alberta as effort recorded through the application underestimated angling effort by a factor of 254. In contrast, effort estimated from online posts to the Nebraska Fish and Game Association's social network was strongly correlated with regional creel estimates ($n = 19$ reservoirs, $r = 0.75$, as reported by Martin et al. 2014), and such information may provide an overall proxy on general reporting compliance (Schwager King 1995). The reasons for the differing relationship between effort estimates from self-reported and creel data for the Alberta lakes versus Nebraska may have been related to reporting being voluntary while using the electronic applications, which could have allowed other societal factors to influence angler decisions to report. Other voluntary reporting systems also provide inconsistent but promising suggestions that some of these data can be used to guide management. For example, another voluntary reporting application, iSnapper, has illustrated that management parameters such as discard rate and fish size can be calculated using a voluntary angler-reported data set. Data collected by the iSnapper angler application provide estimates of catch, fish size, and discard rates statistically similar to those gathered by traditional methods from the Red Snapper *Lutjanus campechanus* fishery in the Gulf of Mexico. Moreover, estimates of harvest derived from traditional creel surveys agreed with iSnapper estimates 83% of the time (Stunz et al. 2014). Collectively, these studies suggest that voluntary self-reporting of harvest on electronic platforms can produce some robust data sets under the right circumstances; however, none of the studies suggested what might happen if effort reporting becomes unnecessary and if electronic reporting of harvest becomes compulsory, which presumably would further increase the precision of these estimates.

The Oregon Department of Fish and Wildlife (ODFW) manages several salmonid fisheries that require a special harvest card in addition to a regular recreational angling license. Anglers are required to record their retained catch on their harvest card to ensure regulatory compliance with bag limits. Although the law requires anglers to purchase a harvest card to validate and record harvest, returning the card to ODFW is optional. Prior to 2018, all harvest cards issued by ODFW were on paper. In December 2018, ODFW began implementing an ELS to effectively administer licenses and harvest cards for hunters and anglers, enhance regulatory enforcement, and reduce operating cost. Customers are now able to purchase and print required fishing credentials from home, 24 h/d, without the delay of submitting and receiving documents by mail. Like those selecting paper harvest cards, anglers who self-select into the electronic option must record their harvest into the mobile application and have it available for review by ODFW or Oregon State Police personnel. However, unlike data from anglers who report harvest on paper cards and voluntarily return their records at the end of the year, electronic harvest input is automatically and instantaneously uploaded and saved to the agency database. This essentially creates real-time compulsory reporting (Newman et al. 1997), thus avoiding the significant reporting bias that can overestimate harvest associated with voluntary paper card returns (Connelly et al. 2000) and reducing noncompliance bias.

Here, we develop an innovative method for estimating recreational harvest that combines capture–recapture estimation techniques with the electronically recorded harvest information from ODFW's ELS, which we term "e-creel." Capture–recapture employs simple ratio estimators to expand sampled individuals to an estimated total, which we define as the total recreational harvest. After deriving our new method, we apply the generalized approach using a case study of the Oregon coastal Chinook Salmon *Oncorhynchus tshawytscha* fishery, which includes four populations of Chinook Salmon that are currently managed under the Pacific Salmon Treaty (PST). We compare the estimates generated with the new e-creel approach to harvest estimated independently using traditional roving creel methods, and we demonstrate that the performance of the new estimator can increase the precision of estimated age- and origin-specific harvest.

METHODS

Derivation of the e-creel harvest estimator.— The e-creel estimator applies pooled Petersen capture–recapture concepts, with harvest data reported to the ELS database used as the tagged population from the first capture event, and recapture data gathered from anglers sampled during abbreviated creel interviews. Unlike information collected in a traditional creel survey, there is no need to estimate effort, which eliminates the need for pressure counts—a primary component of a traditional roving creel design and potential bias.

The Peterson estimator is commonly used to model abundance with a two-sample, single-season capture–recapture event (Ricker 1975). In the first capture event, a known number of individuals are marked and released (n_1). In the second event, the total number of marked individuals that are recaptured (m_2) and the total number of individuals sampled in full (n_2) are recorded. The sampled statistics are then used to construct a set of ratios that are easily solved for the estimated total abundance ($\hat{N}$):

$$\frac{n_1}{\hat{N}} = \frac{n_2}{m_2}, \tag{1}$$

$$\hat{N} = \frac{n_1 n_2}{m_2}. \tag{2}$$

The capture histories (the full set of permutations in which individuals can be observed or not observed) are described by the multinomial distribution and can be modeled by conditioning on the total number of recaptures (r):

$$P\{x_{(i,j)}|r, p_1, p_2\} = \frac{r!}{x_{11}!x_{10}!x_{01}!}\left(\frac{p_1 p_2}{p^*}\right)^{x_{11}}\left[\frac{p_1(1-p_2)}{p^*}\right]^{x_{11}}\left[\frac{(1-p_1)p_2}{p^*}\right]^{x_{11}}, \tag{3}$$

where p^* is the probability that an individual is seen at least once and x is the total number of individuals with the capture history indicated by the subscript. In each capture history, a 1 indicates that the individual was observed at the time step and a 0 indicates that the individual was not observed.

The maximum likelihood estimates associated with this parameterization are

$$\hat{p}_1 = \frac{x_{11}}{(x_{11} + x_{01})}, \tag{4}$$

$$\hat{p}_2 = \frac{x_{11}}{(x_{11} + x_{10})}, \tag{5}$$

$$p^* = \frac{r x_{11}}{(x_{11} + x_{10})(x_{11} + x_{01})}. \tag{6}$$

The subsequent estimate for the total abundance can be written as a function of the estimated capture probability:

$$\hat{N} = \frac{r}{p^*}. \tag{7}$$

The e-creel estimator is based on the parameterization in equation (7). In the e-creel, harvested fish are treated like a single population ($\hat{N}$). The first sampling period is defined by ELS anglers when their harvest cards are validated instantaneously upon being reported in the smartphone application. The second sampling period is defined using abbreviated interview creel data. Electronically harvested fish can be recaptured as the angler leaves the fishery and is intercepted by the creel technician. The primary purpose of the creel technician is to determine whether harvest was recorded using a paper harvest card or an electronic harvest card. Unlike the ELS, harvest is recorded from all anglers regardless of license type, providing a sample statistic and biological data that encompass all harvested Chinook Salmon, including both tagged (ELS-reported) and nontagged (paper-reported) fish. The proportion of fish sampled by the field technician that were reported by anglers using the ELS can subsequently be used to define a recapture probability, providing all elements required for a direct substitution into equation (8):

$$\hat{N} = \frac{m}{p^*}, \tag{8}$$

$$p^* = \frac{m x_{11}}{(x_{11} + x_{10})(x_{11} + x_{01})} = \frac{m^2}{n_1 n_2}, \tag{9}$$

$$\hat{N} = \frac{n_1 n_2}{m}, \tag{10}$$

where N = the total quantity of fish harvested; m = the total quantity of electronically tagged fish that were sampled by technicians; n_1 = the total quantity of fish entered by anglers into the ELS throughout the duration of the fishery; and n_2 = the total quantity of fish sampled by field technicians.

The variance can be derived from Seber (1970):

$$\hat{V}(\hat{N}) = \frac{(n_1 + 1)(n_2 + 1)(n_1 - m)(n_2 - m)}{(m + 1)^2 (m + 2)}. \tag{11}$$

Assumptions.— Our method involved eight assumptions, as follows:

1. Anglers are compliant in reporting harvest electronically (i.e., immediate validation of the harvest card).
2. Harvest reported by ELS anglers and subsequent reporting of the validation method to a creel technician are independent events.
3. Anglers' harvest and license type are reported accurately to creel surveyors.
4. Anglers report harvest locations accurately within the smartphone application.
5. All anglers are equally susceptible to interception while leaving the fishery.
6. The e-creel surveyors obtain a spatially representative random sample of harvested fish across the fishery.
7. The total harvest at the end of the season approximates a closed population.
8. The e-tagging harvest ratios do not differ significantly in time and space within a basin.

Case study: the coastal Chinook Salmon fishery.— The PST is a written agreement between the United States and Canada with the intent to protect, conserve, and manage transboundary salmon stocks. Transboundary stocks are those that travel across international boundaries during their life cycle. The PST forms the principal framework that regulates marine harvest management for all Pacific salmon that are subject to both U.S. and Canadian fishing pressure.

The Chinook Salmon chapter (Chapter 3) of the PST outlines aggregate abundance-based management measures that are intended to sustain natural populations of Chinook Salmon stocks while maintaining fisheries benefits for both U.S. and Canadian entities with agreed allocations between the parties. Escapement indicator stocks (EISs) represent aggregates of escapement composed of similar migration and distribution characteristics for which management goals are set. Two Chinook Salmon stocks are recognized as exploitation rate indicator stocks (ERISs): one from the North Oregon Coast (NOC) aggregate and one from the Mid-Oregon Coast (MOC) aggregate. Robust estimates of age-specific and hatchery- or natural-origin-specific harvest from these indicator stocks are essential PST management requirements; thus, ODFW has maintained annual creel surveys for (1) the Salmon River since the initial ratification of the PST in 1985 and (2) the Elk River following the revised PST that was ratified in 1998. Additional PST management details covering the 2019–2028 agreement are available for download from the Pacific Salmon Commission (https://www.psc.org/about-us/history-purpose/pacific-salmon-treaty/).

The ODFW's Coastal Chinook Research and Monitoring Program (CCRMP) is the scientific party responsible for collecting and evaluating most of the research and monitoring information gathered on coastal Chinook Salmon populations in Oregon. In 2019, the CCRMP conducted creel surveys in four coastal river basins to estimate freshwater recreational harvest of Chinook Salmon. These basins represent the ERISs under the PST for both NOC (Salmon River) and MOC (Elk River) aggregates, as well as two EISs—namely the Nehalem and Siletz rivers (Figure 1). On the Oregon coast, evaluation and monitoring of the two ERISs are based on Chinook Salmon produced at and released from the hatcheries on the Salmon River, representing natural stock from the NOC aggregate, and on the Elk River, representing natural stock from the MOC aggregate. Releases and recoveries are assessed and used to reconstruct the spawning run and harvest rates in the various fisheries. We use the estimated harvest from each of these creel surveys as a base for comparison with the performance of the new e-creel approach. Full sample sizes and data summary statistics for both e-creel and roving creel data sets are available in Table A.1.1. Detailed information on the creel surveying methods is available in Appendix 2.

Cross validation.— Similarity across the harvest estimates derived from independent methodologies was tested using a nonparametric Mann–Whitney U-test, defining the null (H_0) hypothesis as follows: the two methods produce equal estimates of Chinook Salmon harvest.

The test statistic (U) is denoted as the smaller value of U_1 and U_2, defined as

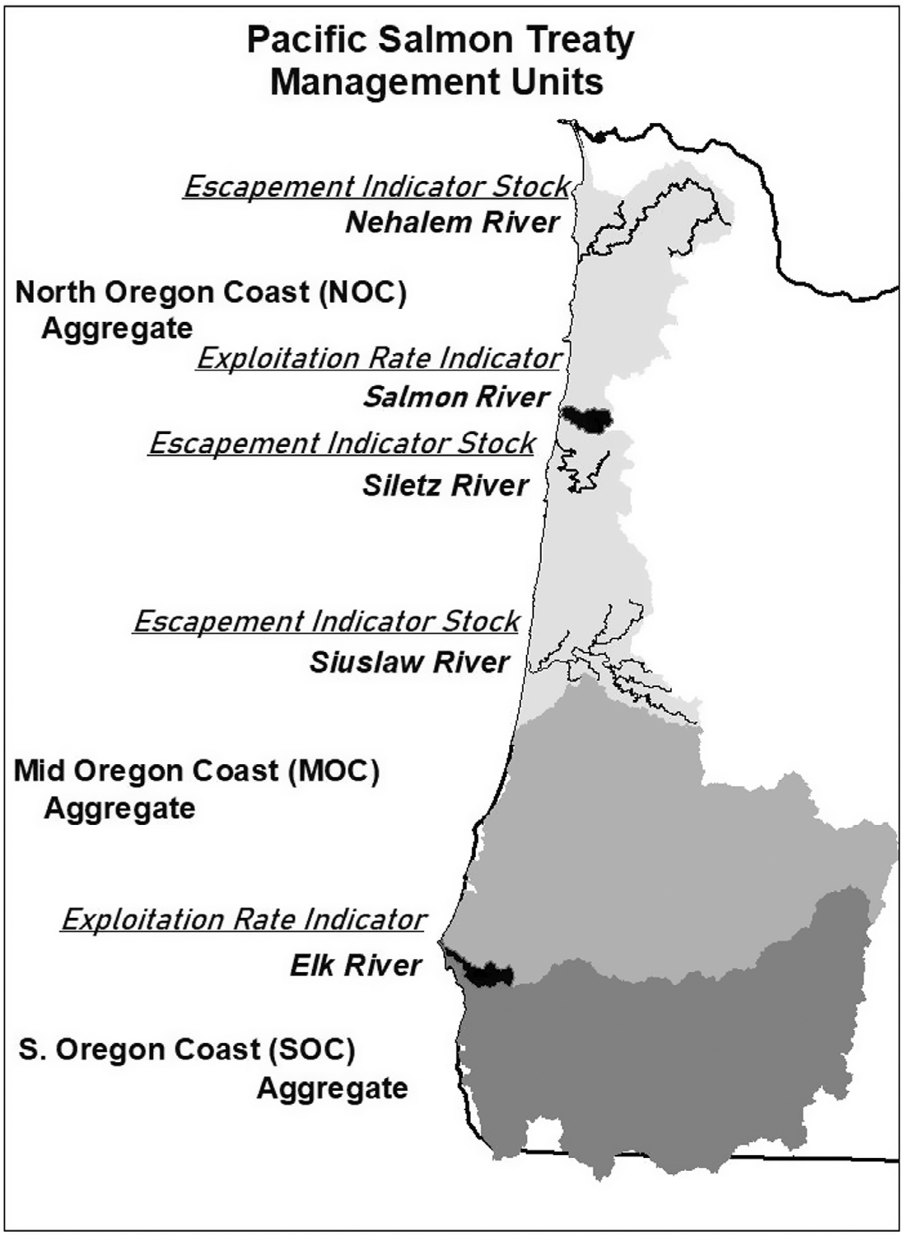

FIGURE 1. Map depicting coastal Oregon Pacific Salmon Treaty fishery monitoring regimes, including all four basins involved in the case study. The Elk and Salmon River basins are highlighted with black fill, representing the exploitation rate indicator stocks for the respective aggregates. The Nehalem and Siletz rivers are also depicted, representing two of the three escapement indicator stocks for the North Oregon Coast aggregate.

$$U_1 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1,$$

$$U_2 = n_1 n_2 + \frac{n_2(n_2+1)}{2} - R_2,$$

where n_1 = the sample size of group 1; n_2 = the sample size of group 2; R_1 = the sum of the ranks for group 1; and R_2 = the sum of the ranks for group 2. We determined a critical value of U such that if the observed value of U was less than or equal to the critical value, we rejected H_0. If the observed value of U exceeded the critical value, we did not reject H_0. Precision was compared by evaluating their relative SEs.

We also compared the relative costs of implementing each method to demonstrate the benefits of a post hoc assessment. The budget was revised to reflect e-creel-specific reductions in personnel and travel cost that were realized through the elimination of pressure counts. Subtracting the e-creel cost from the traditional creel budget resulted in the total estimated savings per basin when utilizing e-creel techniques to estimate harvest. Taking the quotient of the total savings and the summed budget of the traditional creels resulted in an average amount saved per basin.

TABLE 1. Ratio of anglers interviewed by creel surveyors that recorded their fish on the Oregon Department of Fish and Wildlife's electronic licensing system smartphone application by river basin. The average e-tagging ratio of all four study basins in 2019 was 0.307.

Basin location	E-tag sample ratio
Elk River	0.303
Nehalem River and Bay below Highway 26/Elsie	0.309
Salmon River (Coast)	0.282
Siletz River and Bay, South Fork	0.335

TABLE 2. Adult Chinook Salmon harvest estimates and associated SDs from four Oregon coastal river basins in 2019. The e-creel estimates were derived using the Petersen mark–recapture formula. Traditional creel estimates were derived using a stratified, two-stage, roving-access design (see Appendix 2).

	E-creel		Traditional creel	
Basin	Estimate	SD	Estimate	SD
Elk River	565	67	506	196
Nehalem River	1,527	133	1,512	466
Salmon River	1,001	144	1,003	275
Siletz River	1,776	176	1,730	322

RESULTS

Our implementation of an e-creel approach simultaneous to traditional creel surveys has demonstrated both the feasibility and statistical validity of using capture–recapture techniques within a hybrid creel model. By leveraging existing agency data, we were able to compute ratios of electronic harvest cards to paper harvest cards within each of four basins, which were used as an input to derive precise estimates of Chinook Salmon recreational harvest using a Petersen capture–recapture estimator. The sales ratios and proportions of ELS anglers across all four study areas were similar, indicating that the population parameters were stationary through time and space (Table 1). Additionally, the statewide purchase ratio of electronic harvest cards to paper harvest cards (0.289) remained relatively constant in space and time during 2019, lending support that robust, comparable harvest estimates can be generated on an annual basis throughout Oregon's coastal basins without requiring supplemental creel interviews (McCormick 2017). However, quantifying the variance of the harvest estimate for basins without an interview component requires ongoing research.

Both the traditional creel method and the e-creel method produced nearly identical harvest estimates in all four basins (Table 2), yielding an average difference of only 3.4%. The e-creel provided a mean harvest estimate of 1,264 Chinook Salmon (SE = 130), while traditional creel techniques generated a mean harvest estimate of 1,258 Chinook Salmon (SE = 315). Analysis from the Mann–Whitney U-test (α=0.05) indicated that the results were not statistically different ($U = 7$, $n_1 = 4$, $n_2 = 4$, $U_{critical} = 0$, $P = 0.90$). On average ($n = 4$), the e-creel estimate (SE = 65) was 41% more precise than traditional creel estimates (SE = 157).

Post hoc assessment of the 2019 project budgets estimated a 15% cost reduction annually. This is equivalent to average savings of US$24,842 in personnel, operational, and indirect cost per basin by utilizing the e-creel methodology. These savings were primarily attributable to the elimination of effort counts.

DISCUSSION

Our results suggest that using a hybrid creel design consisting of angler-reported ELS harvest data and an abbreviated interview of successful anglers, combined with traditional biological creel sampling, can produce a robust estimate of age- and origin-specific recreational harvest. As illustrated in our case study, the e-creel approach is an efficient and cost-effective replacement for traditional creel surveys and produced comparable estimates. By using a design that eliminates the effort counts required in a traditional creel, for the same costs sampling effort can be redirected to increase encounter rates with anglers, which in turn can increase the precision realized through a capture–recapture estimator (Robson and Regier 1964) while also reducing travel cost (Hansen and Van Kirk 2018).

Underpinning our results is the series of assumptions listed in the development of our methodology, which we believe were met in this case study. In Oregon, regulatory requirements result in what effectively amounts to compulsory harvest reporting by anglers using an electronic license and harvest card. Regulations are enforceable by Oregon State Police Fish and Wildlife troopers who maintain a presence within the fishery and can request the verification of anglers' license and harvest at any time, providing an incentive for anglers to be compliant in validating their harvest cards electronically or on paper depending on the license type (assumption 1). Although some recreational fisheries with mandatory trip reporting can experience low rates of legal compliance (Garvy 2015), this type of noncompliance is more likely associated with fisheries where reporting of effort is necessary to estimate harvest and reporting mandates are new and viewed as excessive, which is not the case with Oregon. Anglers in Oregon have been required to document salmonids harvested since the 1950s but are not required to report trips or harvest, meaning that Oregon anglers are not faced with any new regulations or burdens by purchasing an electronic license. Although compliance is irregularly verified through checks conducted by the Oregon State Police, data to directly verify this assumption were unavailable. Moreover, under the electronic option, reports are uploaded automatically to an agency database without additional actions required by the angler.

Compliance in reporting harvest also relates to our assumption that our capture events are independent (assumption 2). To provide an unbiased estimate, we assume that interactions with a creel surveyor have no bearing on the angler reporting rate and that all fish are reported into the system prior to an angler being interviewed by a creel surveyor (selection into the second recapture sample does not depend on capture in the first; see Williams 2019). Stipulations that harvest can be verified by troopers at any time should decouple the two events and make them independent—but only to the extent that people are compliant (assumption 2). Although we were unable to directly test this potential violation with a direct comparison between specific fish reported in interviews and ELS reports, we did compare the time stamps and total number of fish reported in the ELS database that occurred in the fishing window for intercepted anglers who identified as ELS anglers. Except for two parties that were surveyed on September 18 and October 20, for all of the angling parties reporting to surveyors that they had harvested a Chinook Salmon on an electronic license, there was at least one entry in the system during the time interval in which they had reported fishing (assumptions 1 and 2). Aside from the two noted cases, where fishing intervals among angling parties overlapped, there were always enough recorded fish to cover the combined total number of fish needed to provide coverage across all angling parties, suggesting a minimal observed noncompliance rate of 3% (see Table A.1.2). It is possible that some anglers reported their catch outside the time window of active fishing, such as if they had technological issues (i.e., dead cell phone battery). In this case, the fish would still be within the initial marking event at the conclusion of the season (assumption 7).

Unlike reporting onto an ELS platform during the capture event, the recapture event provides direct interactions between the creel technician and the angler, allowing harvest to be directly validated (assumption 3) regardless of license type. Creel technicians are trained to professionally interview anglers and complete the sampling efficiently, which is known to help eliminate nonresponse error. For example, in the Texas Parks and Wildlife Department's voluntary iSnapper program, noncompliance during interviews of private anglers was estimated as only 4%, supporting the premise that nonresponse bias from anglers being interviewed in person during a recapture event is less problematic and timelier than waiting for responses by mail or phone (Liu et al. 2017). Moreover, with no visual indicator to reveal an angler's license type, there is no reason that the probability of being intercepted would differ between electronic and paper license holders.

In addition to reporting harvest accurately within the ELS, we also assume that the information provided to creel surveyors is accurate and representative of the fishery (assumptions 3, 5, and 6). The sample of angler interviews is randomized, both through the interviewer's selection of people to interview and by using a sampling schedule that covers the fishery spatially and temporally throughout the sampling period (day). Randomization in both time and place ensures that the anglers are representative of the entire fishery. Furthermore, there is no mechanism to bias the recapture population as all anglers are interviewed as they exit the fishery and have no outward mark to suggest their license type (Robson and Regier 1964).

Aside from simply reporting their harvest into the system, the e-creel requires that anglers report the location of their harvest accurately (assumption 4). Within the ELS application, anglers identify their location using a dropdown menu of locations and codes that are correlated with fishing regulations. Similar names between freshwater estuaries and ports likely led to misreporting along both the Siletz and Salmon rivers (i.e., reported to "Siletz Bay" versus "Siletz River and Bay" or reported to "Salmon River" versus "Salmon R [Coast]"). Misreported catch was easy to identify because the ports associated with these rivers are not conducive to marine access and there is essentially no marine Chinook Salmon harvest; thus, all marine harvest recorded from these ports was applied to the freshwater ELS data set. In total, 135 marine records were identified and reclassified as freshwater catch within the Siletz River (23% of all fish electronically recorded for the Siletz River). For the Salmon River, 130 records were changed from marine to freshwater harvest (46% of all fish recorded electronically for the Salmon River). Anglers may be more likely to have inaccuracies while selecting fishing area because it cannot be directly validated and is subject to form recall bias. To avoid this type of bias (Pollock et al. 1994) or to avoid uncertainty, harvest location could be reported "live" with a function that automatically captures geolocation, date, and time.

Spatially biased data can result from a variety of sources ranging from angler demographics to the relative popularity of different locations and how they are addressed in the application and design of any survey (Stunz et al. 2014). Within the ELS, for example, Papenfuss et al. (2015) demonstrated a tendency of self-reported data to underestimate the popularity of a river-dominated region of Alberta, Canada. Jiorle (2015) identified bias due to the absence of riverine locations within the application. To effectively administer the e-creel, spatial documentation from both the ELS and traditional angler interviews must be consistent. This is necessary to negate human error and alleviate the confusion associated with the nomenclature used in selecting a harvest location from the application.

Our last assumption was that the population must also be stationary in space and time (i.e., it must be a closed population). Although harvested fish are continually added throughout the fishing period, the statistic defining the initial marking in the e-creel approach is inverted and defined post hoc after the fishery ends and fish can no longer be added into the harvested population. Stationarity could also be broken if the proportion of anglers using the new ELS differs from the proportion opting for paper licenses/harvest cards throughout the survey period. Although slightly higher ratios were observed as the season progressed, chi-square testing detected no significant differences ($P \geq 0.05$) temporally and there was no plausible mechanism that could create spatial differences across the survey areas (assumption 8). For cases in which this assumption is broken, stratifying the data into time blocks would still permit our hybrid approach to be used, illustrating the versatility of our e-creel.

Protocols and procedures for implementing an e-creel have now been established and documented in CCRMP's e-Creel Operational Plan (ODFW 2021). The e-creel essentially eliminates the effort component of a traditional creel and reduces the interview to one essential question regarding whether harvest was validated electronically or on paper, and biological sampling is maintained. The exclusion of effort counts and the use of simplified interviews allow technicians to intercept anglers throughout the entire duration of the salmon season and throughout the spatial scope of the fishery, minimizing potential bias from varying ratios of e-harvest cards to paper harvest cards over time and space.

The e-creel approach is not subject to most biases of a traditional creel due to the elimination of effort as a component to derive harvest estimates. We should emphasize that traditional creels essentially multiply two functions (CPUE $\times$ effort), both of which are a measure of effort (i.e., catch per angler-hour $\times$ anglers). Biases associated with measures of effort within a traditional creel are of little concern for an e-creel design. If none of the assumptions is violated, an e-creel design will provide a bias-free estimate of harvest that is both cost effective and timely. Within our case study, the harvest estimates derived from the e-creel performed within the guidelines established by the Pacific Salmon Commission's Chinook Technical Committee for nonbiased capture–recapture estimates, which are defined as estimates having coefficients of variation less than 15% (CTC 2013).

The approach that we have derived here may also be extended to populations (river basins) without a supplementary interview by using the statewide sales ratio (0.289) of ELS harvest cards to paper harvest cards. However, this would preclude the use of a Petersen estimator due to the lack of true recapture data, adding uncertainty to the results of a harvest from a basin-specific population. Within the context of our case study, a modified on-site creel design utilizing technicians to interview basin-specific anglers would still be required to gather biological data and scale samples from harvested Chinook Salmon. These data are necessary to apply an appropriate age and origin structure to the harvest estimates and fulfill PST management requirements (CTC 2016). Additionally, quantifying the variance of the harvest estimate for basins without an interview component requires further investigation.

Future work aimed at determining any inherent bias within the hybrid creel estimator needs to be developed. Although in our cross validation we demonstrated that the estimates produced by the e-creel were statistically equivalent to the estimates generated from unbiased traditional creel methods, harvest itself was not censused and the true harvest is unknown, providing no empirical metric to assess the absolute accuracy of either estimate. Simulation work to test how the estimator reacts when each assumption is broken may be valuable for expanding this technique to other fisheries. Optional trip data that could be incorporated into the ELS might include the trip type, angler type, and fishing conditions, which would allow for poststratification and would present a clearer picture of the recreational fishery demographics.

The hybrid creel approach presented here has the potential to remove some of the financial limitations created by traditional creel surveys. In our case study, over

$495,700 were awarded to ODFW in 2019 to conduct traditional creel surveys on four Chinook Salmon populations from coastal Oregon river basins that were either designated as ERISs or EISs for the purpose of PST Chinook Salmon management, with a projected total saving of $74,525 attained through transitioning from traditional creel methods to an e-creel design. Personnel and vehicle costs generally make up most of the savings reported here. However, even greater budget reductions are anticipated once additional administrative efficiencies are identified through time. Although cost may be reduced through the implementation of an e-creel, it will be necessary to maintain some supplemental interview protocols in order to appropriately apply a Petersen estimator and to assure that assumptions are not violated.

Collaborative planning and implementation of fishery sampling for coded wire tags are essential to identify cost-effective solutions to increase the precision of harvest management criteria. A coastwide framework for monitoring and estimating exploitation rates on natural-origin Chinook Salmon impacted by mark-selective fisheries is currently lacking. With mark-selective fishery regulations effective during the 2020 recreational fishery for Chinook Salmon in the Elk River, it is highly desirable to implement an e-creel design that will be efficient and more cost effective in meeting the obligations specified in PST Chapter 3. Introducing efficiencies into our current creel methodology could increase the recovery rate of coded wire tags from fish harvested in both the Elk and Salmon rivers while allowing for greater opportunity to gather appropriate information through the interview process necessary to assess the mark-selective fishery release rates of wild fish. Conventional creel surveys are costly, time consuming, and often limited in space and time. The ODFW's commitment to implement an ELS contributes to a more cost-effective license and harvest tag administration while enhancing regulatory enforcement.

The e-creel approach represents a paradigm shift in the way Chinook Salmon harvest can be monitored. As demonstrated in our case study using data associated with PST management, the e-creel method offers several practical applications and could aid in attaining more cost-effective, timely, and precise harvest estimates as well as generating nonbiased estimates of origin, sex, and age structure for Chinook Salmon at the population level.

ACKNOWLEDGMENTS

We thank our two anonymous reviewers and four internal reviewers—Peter Stevens, Christine Mallette, David Jepsen, and Mark Lewis—for providing valuable input in the preparation of the manuscript. We are also grateful to Sandy Kennedy for providing her competent programming skills to ensure that quality information was attained in a timely manner from our remote field data collection devices. We would like to express our sincere gratitude to Ethan Clemons for his expertise and guidance in developing various research investigations that ultimately led to the implementation of an e-creel design. The entire U.S. section of the Chinook Technical Committee should also be recognized for their support in securing funding for this project. We extend special thanks to Shannon Richardson for her leadership and dedication to promoting conservation research specific to meeting the management objectives for critical Chinook Salmon stocks in coastal Oregon. There is no conflict of interest declared in this article.

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REFERENCES

Bernard, D. R., A. E. Bingham, and M. Alexandersdottir. 1998. Robust harvest estimates from on-site roving-access creel surveys. Transactions of the American Fisheries Society 127:481–495.

Connelly, N. A., T. L. Brown, and B. A. Knuth. 2000. Assessing the relative importance of recall bias and nonresponse bias and adjusting for those biases in statewide angler surveys. Human Dimensions of Wildlife 5:19–29.

CTC (Chinook Technical Committee). 2013. Annual report of catch and escapement for 2012. Pacific Salmon Commission, Report TCCHINOOK (13)-1, Vancouver.

CTC (Chinook Technical Committee). 2016. Chapter 3 performance evaluation report. Pacific Salmon Commission, Report TCCHINOOK (16)-2, Vancouver.

Fisher, M. R. 1996. Estimating the effect of nonresponse bias on angler surveys. Transactions of the American Fisheries Society 125:118–126.

Garvy, K. 2015. The emergence and use of angler self-reporting apps in recreational fisheries. Master's thesis. Duke University, Durham, North Carolina.

Goodman, L. A. 1960. On the exact variance of products. Journal of the American Statistical Association 55:708–713.

Gutowsky, L. F., J. Gobin, N. J. Burnett, J. M. Chapman, L. J. Stoot, and S. Bliss. 2013. Smartphones and digital tablets: emerging tools for fisheries professionals. Fisheries 38:455–461.

Hansen, J. M., and R. W. Van Kirk. 2018. A mark–recapture based approach for estimating angler harvest. North American Journal of Fisheries Management 38:400–410.

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 3:306–317.

Jiorle, R. P. 2015. Determining the utility of electronic, self-reported recreational data for fisheries stock assessment. Master's thesis. University of Florida, Gainesville.

Liu, B., L. Stokes, T. Topping, and G. Stunz. 2017. Estimation of a total from a population of unknown size and application to estimating recreational Red Snapper catch in Texas. Journal of Survey Statistics and Methodology 5:350–371.

Martin, D. R., C. J. Chizinski, K. M. Eskridge, and K. L. Pope. 2014. Using posts to an online social network to assess fishing effort. Fisheries Research 157:24–27.

McCormick, J. L. 2017. Evaluation of methods to estimate salmon harvest using angler harvest permits available on a smartphone application. North American Journal of Fisheries Management 37:1–8.
McCormick, J. L., M. C. Quist, and D. J. Schill. 2013. Self-reporting bias in Chinook Salmon sport fisheries in Idaho: implications for roving creel surveys. North American Journal of Fisheries Management 33:723–731.
Newman, S. P., P. W. Rasmussen, and L. M. Andrews. 1997. Comparison of a stratified, instantaneous count creel survey with a complete mandatory creel census on Escanaba Lake, Wisconsin. North American Journal of Fisheries Management 17:321–330.
NOAA (National Oceanic and Atmospheric Administration). 2019. Marine Recreational Information Program (MRIP), Research and Evaluation Team review of the iAngler and iSnapper reporting programs. NOAA Fisheries, Silver Spring, Maryland.
ODFW (Oregon Department of Fish and Wildlife). 2021. Coastal Chinook Research and Monitoring Program, field operations manual: ELS harvest estimates for Nehalem, Salmon, Siletz, Siuslaw, Sixes and Elk rivers. ODFW, Corvallis.
Papenfuss, J. T., N. Phelps, D. Fulton, and P. A. Venturelli. 2015. Smartphones reveal angler behavior: a case-study of a popular mobile fishing application in Alberta, Canada. Fisheries 40:318–327.
Pollock, K. H., C. M. Jones, and T. L. Brown. 1994. Angler survey methods and their applications in fisheries management. American Fisheries Society, Special Publication 25, Bethesda, Maryland.
Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada 191.
Robson, D. S., and H. A. Reiger. 1964. Sample size in Petersen mark–recapture experiments. Transactions of the American Fisheries Society 93:215–226.
Schwager King, M. A. 1995. Angler effort and harvest of Chinook Salmon by the recreational fisheries in the lower Kenai River, 1994. Alaska Department of Fish and Game, Fishery Data Series 95-12, Anchorage.
Seber, G. A. F. 1970. The effects of trap response on tag recapture estimates. Biometrics 26:13–22.
Stunz, G. W., M. J. Johnson, D. Yoskowitz, M. Robillard, and J. Wetz. 2014. iSnapper: design, testing, and analysis of an iPhone-based application as an electronic logbook in the for-hire Gulf of Mexico Red Snapper fishery. National Oceanic and Atmospheric Administration, Marine Recreational Information Program, Final Report, Silver Spring, Maryland.
Thomson, C. J. 1991. Effects of the avidity bias on survey estimates of fishing effort and economic value. Pages 356–366 *in* D. Guthrie, J. M. Hoenig, M. Holliday, C. M. Jones, M. J. Mills, S. A. Moberly, K. H. Pollock, and D. R. Talhelm, editors. Creel and angler surveys in fisheries management. American Fisheries Society, Symposium 12, Bethesda, Maryland.
Vølstad, J. H., K. H. Pollock, and W. A. Richkus. 2006. Comparing and combining effort and catch estimates from aerial-access designs as applied to a large-scale angler survey in the Delaware River. North American Journal of Fisheries Management 26:727–741.
Williams, B. 2019. Samples, unite! Understanding the effects of matching errors on estimation of total when combining data sources. Doctoral dissertation. Southern Methodist University, University Park, Texas.
Wolter, K. M. 1985. Introduction to variance estimation. Springer-Verlag, New York.
Zarauz, L., J. Ruiz, A. Urtizberea, E. Andonegi, E. Mugerza, and I. Artetxe. 2015. Comparing different survey methods to estimate European Sea Bass recreational catches in the Basque country. ICES (International Council for the Exploration of the Sea) Journal of Marine Science 72:1181–1191.

SUPPORTING INFORMATION

Additional supplemental material may be found online in the Supporting Information section at the end of the article.

Appendix 1: Summary Tables of Siletz River Creel Data Depicting Sample Sizes and Addressing Assumptions and Bias

TABLE A.1.1. Sampling statistics summarizing Siletz River, Oregon, e-creel data and statewide licensing sales in 2019.

Description	Statistic
Total number of anglers intercepted on the Siletz River, 2019	797
Total number of electronic licenses statewide during the survey period	90,519
Total number of paper-licensed anglers statewide	202,071
Total number of Chinook Salmon e-harvest records from the Siletz River	595
Total number of Chinook Salmon sampled	191
Total number anglers reporting harvest on e-tag	64

TABLE A.1.2. Data summary of the total number of Chinook Salmon observed as harvested by creel surveyors within angler-reported fishing windows among anglers who reported having an electronic license compared to the total records within the Oregon Department of Fish and Wildlife's electronic licensing system (ELS) across the same day and time period. These data support the assumption of independence (see Methods).

	Fishing window			
Date	Trip start time (hours)	Trip end time (hours)	ELS creel harvest	ELS fishing window
Aug 30, 2019	1030	1700	2	2
	1500	1735	1	2
Sep 9, 2019	0700	1340	1	1
	0630	1435	3	4
Sep 10, 2019	0600	1420	1	4
Sep 15, 2019	0630	1045	2	3
	0645	1130	1	3
	0700	1430	1	5
Sep 17, 2019	0700	1151	1	6
	0645	1238	4	7
Sep 18, 2019	0715	1006	2	1
	0700	1436	1	3
Sep 21, 2019	0630	1153	1	4
	0533	1413	1	4
	0630	1630	1	4
Sep 22, 2019	0631	1241	1	6
	0700	1407	1	6
	0635	1435	1	6
Sep 25, 2019	0715	0921	1	3
Sep 26, 2019	0710	0910	3	5
	0718	0918	1	5
	0703	1333	1	15
	0630	1421	1	15
	0635	1435	2	15
Sep 27, 2019	0800	1345	1	15
	0700	1347	3	15
	0630	1400	2	15
	0800	1410	3	16
	0957	1502	1	21
	0630	1620	2	22
	0715	1652	3	22
Sep 29, 2019	0854	1554	1	3
	0708	1608	1	3
	0738	1638	1	3
Oct 1, 2019	0817	1217	1	3
	0700	1442	1	3
	0730	1546	2	4
Oct 4, 2019	0706	1656	1	5
Oct 9, 2019	0830	1630	1	5
	0730	1640	2	5
Oct 11, 2019	0708	1408	2	4
	0713	1413	2	4
Oct 13, 2019	0703	1133	1	4
Oct 20, 2019	0715	1440	2	1
Oct 21, 2019	0730	1407	1	10

TABLE A.1.2. Continued.

Date	Fishing window		ELS creel harvest	ELS fishing window
	Trip start time (hours)	Trip end time (hours)		
Oct 23, 2019	0730	1349	3	10
	0730	1502	1	10
Oct 26, 2019	0735	1435	3	8
	0730	1510	1	9
Nov 3, 2019	0900	1446	1	2
Nov 7, 2019	0930	1521	1	1

Appendix 2: Creel Methods Within the Coastal Chinook Salmon Fishery

The traditional creel followed a stratified roving-access creel design set up in two stages to account for the extensive geographic area of the fishery. Estimated harvest per sample day in a particular stratum was calculated using angler effort and catch-per-effort metrics from completed angler trips to remove length-of-stay bias (Pollock et al. 1994; Bernard et al. 1998):

$$\hat{H}_i = \hat{E}_i \overline{\text{CPUE}_i}, \tag{A.2.1}$$

where i = the sampling days, $\hat{E}_i$ = estimated effort, and $\overline{\text{CPUE}_i}$ = average CPUE.

Angler effort was derived from instantaneous angler counts, with sampling periods equal to the length of the fishable day. The average CPUE was estimated as the ratio of means (Hoenig et al. 1997):

$$\overline{\text{CPUE}_i} = \frac{\sum_{k=1}^{m_i} h_{ik}}{\sum_{k=1}^{m_i} e_{ik}}, \tag{A.2.2}$$

where k = individual anglers, m = the number of anglers interviewed, h = the number of fish caught during fishing trips in which anglers were interviewed, and e = the length (h) of fishing trips of interviewed anglers.

Variance of the CPUE was estimated as (Bernard et al. 1998)

$$v\left(\overline{\text{CPUE}_i}\right) = \frac{\sum_{k=1}^{m_i} \left(h_{ik} - e_{ik}\overline{\text{CPUE}_i}\right)^2}{\bar{e}_i^{-2} m_i (m_i - 1)}. \tag{A.2.3}$$

Temporal stratifications were also employed to mitigate day-type bias associated with increased angler effort during the weekends, and angler trips were poststratified by angler type to account for significantly higher catch rates enjoyed by anglers whose trips were guided. The number of fish harvested by catch area and month stratum was defined as

$$\hat{H} = D \frac{\sum_{i=1}^{d} \hat{H}_i}{d}, \tag{A.2.4}$$

where d = the number of sampled days in the stratum and D = the total available sampling days in the stratum.

Daily angler-hour effort was estimated as

$$\hat{E}_i = T \frac{\sum_{t=1}^{r} x_{it}}{r}, \tag{A.2.5}$$

where t = an individual angler count during the sampling period, x = total number of anglers in the effort count, r = the number of effort counts per day, and T = the length of the sampling period (fishable day length).

Since effort was determined systematically, the variance equation was described by (Wolter 1985)

$$v\left(\hat{E}_i\right) = T^2 \frac{\sum_{t=2}^{r} \left[x_{it} - x_{i(t-1)}\right]^2}{r^2 (r-1)}. \tag{A.2.6}$$

The variance of the daily harvest was derived by the method of Goodman (1960, as cited by Bernard et al. 1998):

$$v\left(\hat{H}_i\right)=\hat{E}_i^2\left(\overline{\mathrm{CPUE}_i}\right)+\mathrm{CP\bar{U}E}_i^2 v\left(\hat{E}_i\right)-v\left(\mathrm{CP\bar{U}E}_i\right)v\left(\hat{E}_i\right), \tag{A.2.7}$$

and the variance for each harvest/month stratum was

$$v\left(\hat{H}\right)=D(D-d)\frac{s_1^2}{d}+\frac{D}{d}\sum_{i=1}^{d}v\left(\hat{H}_i\right), \tag{A.2.8}$$

where $s_1^2=\frac{\Sigma\left(\hat{H}_i-\bar{\hat{H}}\right)^2}{d-1}$.

Total harvest was estimated as the sum of all harvest in each stratum, and the total variance of the harvest was estimated as the sum of all stratum variances (Pollock et al. 1994).