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ARTICLE

Evaluation of Creel Survey Methods to Estimate Recreational Harvest of Surf Smelt in Puget Sound, Washington

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Abstract
Fisheries for Surf Smelt *Hypomesus pretiosus* in the inland marine waters of Washington State are currently managed under the assumption that annual recreational harvest is roughly similar to commercial harvest. Commercial harvest is monitored by submission of mandatory fish tickets that document sales to licensed vendors. Assessment of recreational effort and harvest is complicated by (1) the lack of a licensing requirement for fishers, (2) the fact that fishing occurs throughout the year but tends to peak during locally specific time windows, and (3) the ability of anglers to engage in the fishery from private shorelines in addition to public access points (e.g., boat ramps). To adequately estimate recreational harvest, a survey method must be developed that accounts for spatiotemporally diverse harvest patterns. Here, we report the results of a pilot study that combined access-point and roving, boat-based creel survey techniques to sample a known region of high recreational fishing pressure during the traditional fishing "season" for Surf Smelt. In addition to providing a statistically valid estimate of harvest at these locations, we described patterns of both fishing effort and catch across time, in association with various environmental variables, and at public access points and private beaches. We found that based on the site-specific estimates generated here and the number of high-use recreational fishing sites in Puget Sound, Surf Smelt harvest has the capacity to exceed the level that has been assumed for purposes of management. We conclude that combining access-point surveys and roving creel counts represents a logistically feasible and cost-effective method for estimating recreational harvest of Surf Smelt throughout Puget Sound or harvest in any other fishery with similarly complex spatiotemporal participation.

Forage fish serve as an energy conduit between primary producers/low-level consumers and upper-level predators (Rice 1995; Trites 2003; Brand et al. 2007; Dufault et al. 2009; Smith et al. 2011) and are generally highly abundant, schooling, small bodied, prolific, and high in lipid content (Van Pelt et al. 1997; Robards et al. 1999; Anthony et al. 2000; Abookire and Piatt 2005). In Puget Sound, Washington, the forage fish species complex consists of Pacific Herring *Clupea pallasii*, Pacific Sand Lance *Ammodytes hexapterus*, Northern Anchovy *Engraulis mordax*, Pacific Sardine *Sardinops sagax*, and a variety of smelt species (Osmeridae; Emmett et al. 1991; Penttila 2007); however, evidence suggests that the composition of this community has changed substantially in recent decades (Rice et al. 2012).

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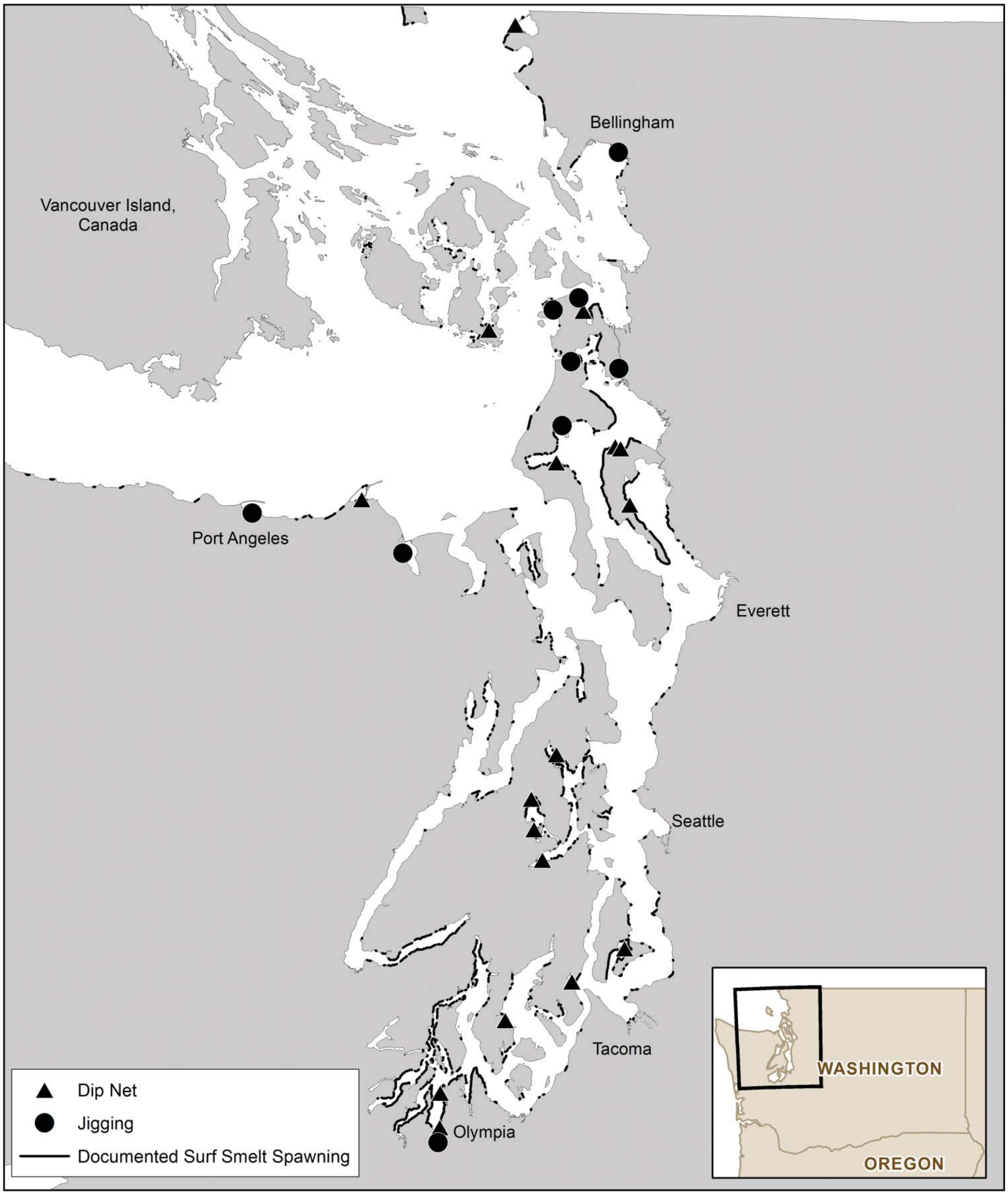

FIGURE 1. Locations of documented Surf Smelt spawning grounds and popular recreational fishing sites in Puget Sound, Washington.

Surf Smelt *Hypomesus pretiosus* are ubiquitous intertidal spawners on Puget Sound beaches (Figure 1; Rice 2006; Penttila 2007; Quinn et al. 2012). Spawning occurs throughout the year on a Puget Sound-wide basis, but in a given locale the peak spawning window is generally 3–4 months long (Penttila 2000). Harvest of Surf Smelt occurs via beach (drag) seine in the commercial fishery and via dip net in the recreational fishery; the fish are harvested when they aggregate in nearshore waters to spawn. Additional recreational harvest of nonspawning Surf Smelt occurs year-round via rod-based jigging from piers and boats throughout Puget Sound (Figure 1). An understanding of the extent to which Surf Smelt and other ecologically important forage species are exploited for human use is vital to the future management of the Puget Sound ecosystem, but to date little research attention has been directed toward forage species, with the exception of Pacific Herring (Gustafson et al. 2006; Stick and Lindquist 2009). Additionally, Washington State's Forage Fish Management Plan advocates for a conservative approach to exploitation of forage species, including Surf Smelt (Bargmann 1998); as such, development of a Puget Sound-wide assessment model for Surf Smelt recreational harvest is warranted if fishing is to proceed in a manner consistent with this plan.

Surf Smelt commercial harvest, which is documented by wholesale buyers on fish-receiving tickets, has averaged approximately 41,500 kg annually since 2000 (Washington Department of Fish and Wildlife [WDFW], unpublished data). Fishing effort and harvest in recent years have been concentrated along the northwestern shoreline of Camano Island, Washington; Marine Fish Catch Reporting Areas 24A and 24C include these harvest locations (Figure 2) and have accounted for an average of 73% of the reported landings since 2000 (WDFW, unpublished data). The concentration of commercial fishing effort and observed significant recreational fishing effort in this region (WDFW, unpublished data) resulted in its selection as the study area for initial methods testing. Recreational harvest of Surf Smelt is not currently monitored and has simply been assumed to be roughly comparable to commercial harvest. Past estimates of harvest at high-use sites suggest that 3,490 kg of Surf Smelt are taken by dipnetting (Wildermuth 1993) and 6,350 kg are taken by jigging (Hoffman and Palsson 1990) at single-area sites over the course of a several-month-long season. For management purposes, Surf Smelt recreational harvest in Puget Sound is currently assumed to be 45,360 kg annually. Recreational dip-net fishing occurs alongside commercial harvest on the northwest shore of Camano Island, with two public access sites dominating the fishing activity (Figure 2).

A recreational fishing license is not required to harvest Surf Smelt in Washington, making estimation of the overall number of participants in the fishery exceedingly difficult. Other recreational marine fisheries in the state require a license, which allows for baseline telephone surveys to evaluate fishing effort and catch. Harvest estimation is further hindered by the spatiotemporally dispersed nature of Surf Smelt spawning and by the ability of anglers to engage in the fishery directly from shore rather than from a boat. For localized areas, the spawning period may be well documented and temporally discrete, but peak spawn timing and distribution vary across the entire year on the geographic scope of Puget Sound (Penttila 2000). These fishery and biological factors mean that (1) access via both public and private beaches must be factored into any estimate of fishing effort or harvest, (2) localized effort may be focused during a distinct season when fish are abundant in the nearshore areas, and (3) survey "control points" (e.g., boat ramps and piers) that are used in traditional recreational fishery surveys are of reduced utility in this case. Jigging is often used to harvest juvenile Surf Smelt, whereas dipnetting targets actively spawning fish; therefore, dipnetting was the exclusive focus of the present study because the harvest methods, timing, and locations differ substantially between gear types.

We used the survey design of Hoenig et al. (1993) to collect data from public access points (i.e., county parks) and private beaches along northwest Camano Island in order to estimate Surf Smelt recreational harvest over the course of the traditional fishing season (WDFW, unpublished data). Estimation of harvest and fishing effort by combining interview data from complete fishing trips with roving samples of incomplete trips across a broader geographic area is a common practice in both marine and freshwater systems (Pollock et al. 1997; Viega et al. 2010). At all locations selected for this study, the Surf Smelt fishery typically occurs from June through October at high slack tides during both night and day (Penttila 1978, 2000, 2007) and is limited by regulation to 5 d/week (the fishery is closed from 0800 hours Wednesday through 0800 hours Friday). This study was performed with the specific intent of adapting the survey design after one season, considering both data validity and cost efficiency, and expanding survey efforts in subsequent years. Our specific goals were to (1) develop a cost-effective sampling protocol to estimate total Surf Smelt harvest from both private beaches and public access points in a specific location; (2) estimate total harvest at two public access points that are popularly used for Surf Smelt dipnetting; (3) estimate total harvest along a predefined coastline at private beaches adjacent to the public access sites; (4) estimate the uncertainty of the total catch estimate by bootstrapping, with a target coefficient of variation (CV) of 15% for each estimate; and (5) describe diurnal and tidal patterns of recreational fishing effort and angler behavior.

STUDY SITE

To estimate recreational harvest of Surf Smelt, we conducted a study using the design of Hoenig et al. (1993) at two access sites known for Surf Smelt harvest on northwest Camano Island: Maple Grove County Park and Utsalady County Park (Figure 2). These sites lie approximately 65–95 km northwest of the highly populated Seattle and Everett metropolitan areas in Washington and are frequented by both local and visiting fishers. The established "traditional" harvest window for Surf Smelt in this area extends from late June through October, although spawning does occur in the region during other times of the year (WDFW, unpublished data). Both of the survey sites are characterized by public beaches located adjacent to numerous small, private beaches that dominate the shoreline for 15.3 km from Onamac Point to Brown Point (Figure 2). The accessible public fishing area is approximately 145 m long at Utsalady Park and roughly 70 m at Maple Grove Park.

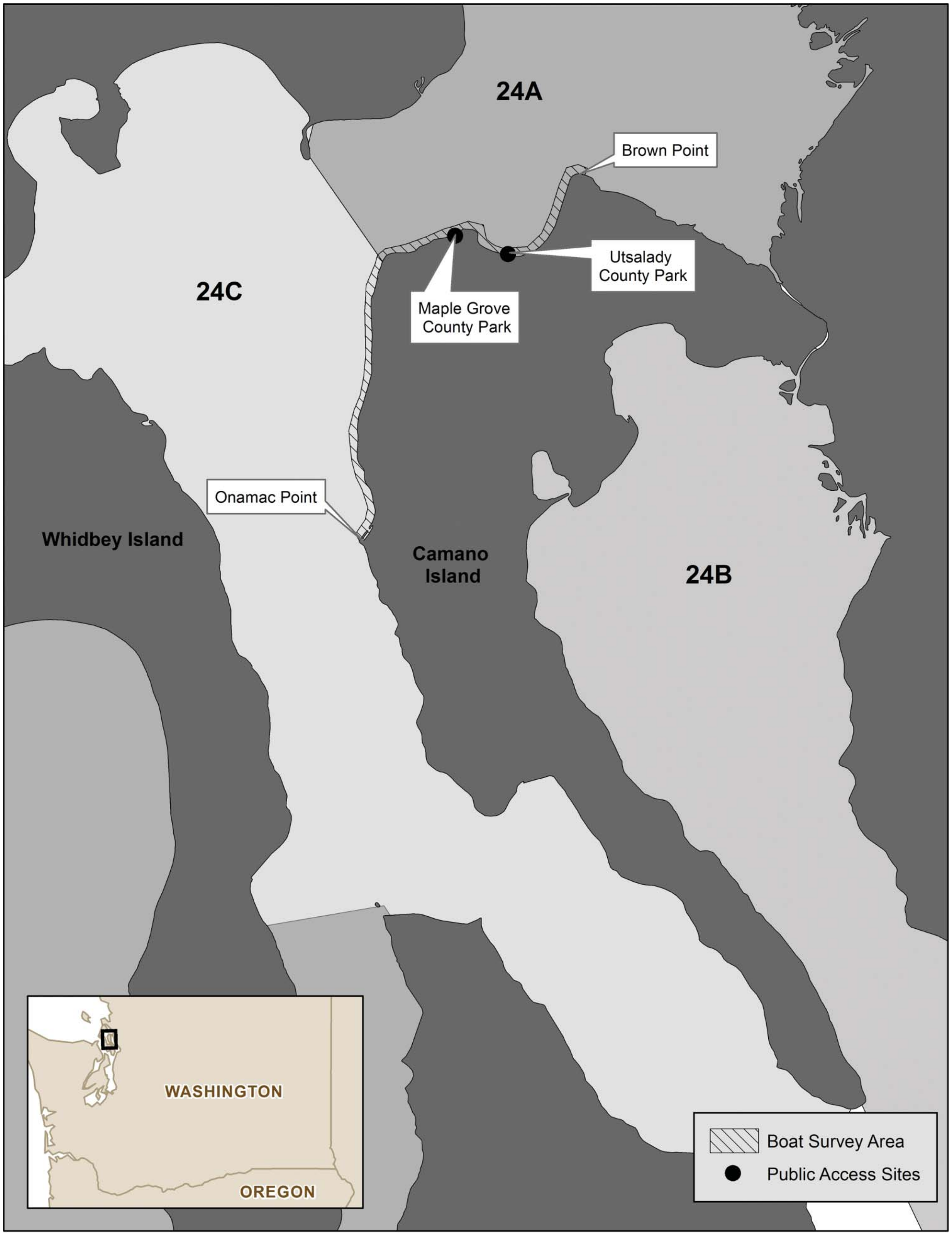

FIGURE 2. Locations of the study area along northwest Camano Island, Washington, and the Marine Fish Catch Reporting Areas used for monitoring the commercial harvest of Surf Smelt. The access points surveyed in this study (Maple Grove County Park and Utsalady County Park) are labeled, and the area surveyed by boat is highlighted in crosshatching.

METHODS

Angler interviews at public fishing sites.—To validate the assumption that fishing was not occurring at public access sites during the night, angler surveys during the first month of sampling were conducted across a randomly selected set of high-tide windows during all open fishing periods (i.e., from 0800 hours Friday through 0800 hours Wednesday). Both parks are closed at sunset, and nighttime fishing effort was expected to be minimal or nonexistent. Sampling effort was split evenly between the Maple Grove Park and Utsalady Park access sites and between weekday (1800 hours Sunday through 0800 hours Wednesday) and weekend (0800 hours Friday through 1800 hours Sunday) tides. A high-tide window was defined as 1 h before the predicted high tide until 2 h after the high tide or until all anglers had left the location.

Initial sampling began on July 23, 2012, with a total of eight sample periods scheduled per week (two weekend and two weekday sample periods at each park). The sampler interviewed exiting anglers only (i.e., complete trips) and recorded fishing start and end times as well as the total weight (g) or count of Surf Smelt caught. The average air temperature during each tidal window was also recorded along with a coded, qualitative assessment of weather condition (e.g., overcast, raining, or sunny). When possible, a random sample of 30 individual Surf Smelt per sample period was measured (SL, nearest mm) and weighed (nearest g). When counts of Surf Smelt were collected without weights, they were converted to an estimated weight after the study was complete by using the mean individual fish weight determined over the course of the study.

After 1 month of surveys, no anglers were observed to initiate fishing after 2130 hours, and the sampling frame was therefore adjusted to include only high tides occurring between 0800 and 2200 hours. The total number of sample periods per week was reduced from eight to six, split evenly between day types and between access sites. The sampling protocol was also adjusted such that sampling occurred from 15 min before high tide to a minimum of 2 h after high tide (if no fishers were present) and a maximum of 3 h after high tide. Incomplete-trip interview data were collected from anglers that were still fishing 3 h after high tide. Sampling in accordance with these survey parameters continued until the end of October 2012.

Angler counts by boat.—Shoreline surveys using a 4.3-m, outboard, rigid-hull inflatable boat were conducted along a 15.3-km stretch from Brown Point to Onamac Point on Camano Island (Figure 2) to identify and interview anglers who were fishing from private beaches during randomly selected high tides. Global Positioning System waypoints were collected and used to determine the total lineal shoreline sampled with measurements in GIS for public versus private shoreline lengths and high-bank (difficult access) versus low-bank (easy access) shoreline lengths. Start location within the survey frame was randomly selected from one of eight evenly sized shore segments for each survey day, and the entirety of the survey area was progressively sampled during each selected high-tide window.

Boat surveys began on August 5, 2012, and were scheduled for one weekday high tide and one weekend high tide per week. Due to safety considerations and a lack of fishing effort during nighttime high tides, only tides occurring between dawn and approximately 1 h after dusk on days open for recreational fishing were considered for sampling.

Two counts of angler effort were made per survey day: the first started at high tide, and the second started approximately 1–2 h after high tide. Completion of the boat route took approximately 30 min (excluding stops to interview anglers) under calm water conditions. Roughly 5 min were allowed per interview stop. Data collected from each interviewed angler included the count of Surf Smelt caught, whether the fisher was a private owner or guest/other, the fishing start time, the interview time, and the fishing location (GPS). Due to challenges associated with contacting fishers on private beaches (e.g., trespass laws), observed catch was not sampled for fish length or weight, and the size composition of the catch was assumed to be similar to that at public sites.

Angler preference and behavior analysis.—Application of this pilot study's results to the development of a Puget Sound-wide assessment of Surf Smelt recreational harvest requires an understanding of patterns in angler behavior and fishing effort. Although these patterns likely vary across locations due to human demographics, site accessibility, and Surf Smelt distribution, only one other study of a high-use recreational Surf Smelt dipnetting beach (Ross Point, Sinclair Inlet, Puget Sound) currently exists for comparison (Wildermuth 1993). Results from Wildermuth (1993) and from the current study will be used to inform levels of and locations for future sampling effort to produce a representative and unbiased estimate of fishing effort and harvest.

To evaluate the appropriateness of the selected sampling window for capturing angling effort at each access site, the fishing start time and end time for each interview were first standardized to the time of high tide. A two-way ANOVA was then performed for each of these timing variables by using site and day type (i.e., weekend versus weekday) as fixed factors. The analysis was further refined by considering only successful angling trips in a second two-way ANOVA to describe the timing attributes of trips that contributed directly to harvest; site and day type were again used as fixed factors. A similar analysis could not be performed for samples from private beaches due to the small sample size and because we did not collect end fishing times for those individuals.

Detailed patterns in angler behavior across the season, between parks, and relative to several environmental variables were assessed using two types of analysis, depending on the nature of the predictor variables involved. For numerical variables (e.g., tidal height and air temperature), correlation analysis was applied. For categorical variables (e.g., weather condition), two-way ANOVAs were employed. Site (i.e., Maple Grove Park versus Utsalady Park) was included as a fixed factor in all models, and time period, weather condition, day type, and day of the week were each evaluated in separate tests. A multiway ANOVA simultaneously considering all categorical variables could not be performed because sample size was insufficient to provide combinations of all possible variables (i.e., it was an incomplete design with missing cells; Zar 1999). Data from public access sites and private beaches were not combined for analysis, and conclusions were drawn separately for angler behavior in each of these location strata. All ANOVAs were conducted using SYSTAT version 13.

Harvest and effort estimation.—Sampling of diverse beach types, times of day, days of the week, months, and weather conditions allowed for in-depth investigation of fishing effort and harvest patterns in the survey area. From the gathered data, we calculated the total observed catch in each target area by month strata. We subsequently generated expanded catch for each target area. Harvest was estimated by catch expansion rather than by multiplication of average catch per unit effort and total effort because our survey design involved few interview questions and avoided the correlation between survey catch and survey effort in variance estimation of total catch.

Access-point survey.—For each interviewed angler i, tide j, survey period k, day type l (i.e., weekday versus weekend), and park m, we let

n_{klm} = the total number of high tides,
s_{klm} = the number of high tides surveyed,
E_{jklm} = the total number of encountered anglers that were surveyed, and
C_{ijklm} = the catch (weight, kg).

The estimated total catch from the access-point survey was calculated as

$$\hat{C}_A = \sum_m \sum_l \sum_k \sum_j \sum_i C_{ijklm}. \qquad (1)$$

Equation (1) only applies for a full census of all available sampling periods, but this is unlikely to occur in the field because of adverse weather conditions, the cost involved, or both. Ideally, there is no variance for $\hat{C}_A$. In this study, we randomly allocated 80% of the total sampling effort to surveys at access points based on a high expected encounter rate for fishers at these sites and taking into account manpower limitations and other logistics. Without knowing the distribution of fishing effort between the two parks, 40% of the total sampling effort was allocated to each park. For each survey period k, day type l, and park m, we randomly selected s_{klm} out of n_{klm} high tides to conduct the access-point surveys. Thus, $\sum_i C_{ijklm}$ is the total catch at tide j, survey period k, day type l, and park m; $\sum\sum_i C$ is the total catch of s_{klm} surveyed high tides. Therefore,

$$\hat{C}_A = \sum_m \sum_l \sum_k \frac{n_{klm}}{s_{klm}} \sum_j \sum_i C_{ijklm}. \qquad (2)$$

Similarly, we estimated the total number of anglers from the access-point survey as

$$\hat{E}_A = \sum_m \sum_l \sum_k \frac{n_{klm}}{s_{klm}} \sum_j E_{jklm}. \qquad (3)$$

As our survey spanned a single harvest season and produced single stratum-specific estimates for both catch and effort, variation could not be empirically determined based solely on sample data. We estimated the 95% confidence interval (CI) and the CV by bootstrapping the catch and effort estimates with 10,000 replicates. The use of bootstrapping instead of parametric methods can avoid negative CI estimates (Hall 1992; Jackson and Cheng 2001). The CV was estimated by taking the mean quantile values of 1 SD from the median on both sides and dividing by the estimated total catch or effort, respectively.

Roving creel survey.—For each interviewed angler i, tide j, survey period k, and day type l, we let

t = the length of the fishing period (h) for each high tide,
m_{jkl} = the average time (h) to complete one roving creel survey,
n_{kl} = the total number of high tides,
s_{kl} = the number of high tides surveyed,
A_{jkl} = the total number of encountered anglers that were surveyed,
C_{ijkl} = the total catch (weight, kg),
$\hat{E}_{kl}$ = the estimated mean number of anglers,
L_{ijkl} = the length of incomplete fishing effort (h),
R_{ijkl} = the recorded incomplete catch (kg), and
T_{jkl} = the total fishing time (h).

The observed incomplete catch R_{ijkl} is a uniform random variable with a mean equal to $C_{ijkl}/2$ and a variance equal to $C^2_{ijkl}/12$ (Hoenig et al. 1997). Similarly, the observed incomplete fishing time L_{ijkl} has a mean of $T_{ijkl}/2$ and a variance of $T^2_{ijkl}/12$. The estimated total number of anglers fishing during tide j, survey period k, and day type l was (Hoenig et al. 1993)

$$\hat{E}_{jkl} = \frac{t}{m_{jkl}} A_{jkl}. \qquad (4)$$

The estimated total catch at each surveyed high tide was

$$\hat{C}_{jkl} = \frac{t}{m_{jkl}} \sum_i C_{ijkl} = \frac{2t}{m_{jkl}} \sum_i R_{ijkl}. \tag{5}$$

Due to logistical constraints (e.g., funding and field conditions), it is usually impracticable to complete all roving creel surveys on all high tides within a given time period. As such, we allocated 10% of total survey effort for each day type l. Assuming s_{kl} (n_{kl}) selected high tides, the estimated total catch from the roving creel survey ($\hat{C}_B$) was

$$\hat{C}_B = \sum_k \sum_l \frac{n_{kl}}{S_{kl}} \sum \hat{C}_{jkl}. \tag{6}$$

Similarly, the total estimated fishing time for all anglers based on the creel survey ($\hat{T}_B$) was

$$\hat{T}_B = \sum_k \sum_l \frac{n_{kl}}{S_{kl}} \sum \hat{T}_{jkl}. \tag{7}$$

The estimated number of all anglers based on the creel survey ($\hat{E}_B$) was

$$\hat{E}_B = \sum_k \sum_l \frac{n_{kl}}{S_{kl}} \sum \hat{E}_{jkl}. \tag{8}$$

The 95% CIs and CVs of all final parameter estimates from the roving boat surveys were estimated by bootstrapping with 10,000 replicates. Bootstrapping was conducted three times with progressively larger sample sizes, and the precision of the estimates was compared to 2.50, 15.87, 84.13, and 97.50% quantiles. This procedure provided validation that the bootstrapped estimates followed a predictable underlying distribution, and the selected quantiles assumed a normal distribution. The estimates of the quantiles were correct to the first two significant places.

RESULTS

Effort and Harvest at Public Sites

In total, 97 high-tide sample windows were surveyed between July 23 and October 30, and 636 anglers were interviewed. Of these, 422 (66.4%) anglers were successful in capturing Surf Smelt. Total observed fishing effort at Utsalady Park (547 interviews) was almost three times higher than observed fishing effort at Maple Grove Park (183 interviews; Figure 3). Angler effort was highest during the first week of August, with a secondary peak from August 27 through September 16 at both sites. Total observed catch was 812.75 kg, with 62.4% coming from Utsalady Park and the remainder coming from Maple Grove Park. This harvest discrepancy is smaller than might be expected given effort levels and the difference in site size, presuming that the harvest rate per angler is similar between the two sites. Overall harvest per angler, however, was not equal and averaged 1.72 kg at Maple Grove Park but only 0.90 kg at Utsalady Park. Of the 422 successful anglers, 54 (12.8%) had harvested more than their 4.5-kg daily legal limit. Twenty-nine of these overharvest events occurred at Utsalady Park, and 25 occurred at Maple Grove Park. The highest average catch rate was observed during the week of August 13–19 at Maple Grove Park and the week of September 10–16 at Utsalady Park (Figure 3). Note, however, that peak harvest rate at Maple Grove occurred during a week in which a single, highly effective fisher was surveyed. When this outlier was removed from calculations, average harvest per angler at Maple Grove Park became 1.70 kg—still considerably higher than at Utsalady Park.

The expanded estimate of harvest over the course of the study was 1,047.13 kg for Utsalady Park and 610.50 kg for Maple Grove Park; the combined total harvest was 1,657.63 kg (Table 1). Harvest during specific combinations of day type and survey period at either site tended to have small sample sizes and relatively large CVs, but overall CVs were 7.21% for Utsalady Park, 11.20% for Maple Grove Park, and 5.54% combined. The expanded estimate of fishing effort over the course of the study indicated that approximately 964 angler trips occurred at Utsalady Park and approximately 352 trips occurred at Maple Grove Park, for a total of 1,316 trips (Table 2). Estimated CVs for fishing effort were lower than those for harvest (Utsalady Park: effort CV = 3.39%; Maple Grove Park: CV = 6.83%; combined: CV = 1.84%). This disparity in CVs reflects the different sources of variation influencing the two parameters: harvest variation stems from variation in fish abundance, which can fluctuate substantially, whereas variation in effort stems from angler abundance, which is more level. Overall CVs for all harvest and effort estimates were lower than our target CV of 15%, thus indicating that sampling effort could be scaled back somewhat at public access sites while retaining the ability to generate statistically valid harvest estimates.

Angler Behavior at Public Sites

Considering interview data from both of the public access sites, the average fishing start time was 0.12 ± 1.34 h offset from high tide (mean ± SD; i.e., start time occurred roughly 7 min after high tide, give or take 1 h and 20 min). When start time was considered separately for each site, differences between the two locations became apparent (Maple Grove Park: $\bar{x} = -0.60 \pm 1.38$ h [i.e., 0.60 h before high tide]; Utsalady Park: $\bar{x} = 0.40 \pm 1.21$ h; df = 1, $F = 79.61$, $P < 0.001$; Figure 4, light-gray series). The same was true for end time, which differed between the two sites (Maple Grove Park: $\bar{x} = 1.46 \pm 0.92$ h; Utsalady Park: $\bar{x} = 2.32 \pm 0.80$ h; df = 1, $F = 128.26$, $P < 0.001$; Figure 4, dark-gray series). Day type

TABLE 1. Total estimated Surf Smelt recreational catch by site and day type (i.e., weekend versus weekday) along northwest Camano Island, Washington. The weekend was defined as spanning the window from 0800 hours on Friday through 1800 hours on Sunday; the weekdays spanned from 1800 hours on Sunday through 0800 hours on Friday. The fishery was closed on Wednesdays and Thursdays (CI = confidence interval; CV = coefficient of variation).

Site	Day type	Total catch (kg)	95% CI	CV (%)
Utsalady Park	Weekend	700.21	359.13–1,050.65	27.58
	Weekday	346.92	157.65–579.77	31.43
	Total	1,047.13	901.80–1,206.97	7.21
Maple Grove Park	Weekend	274.15	76.76–530.84	42.34
	Weekday	336.35	152.08–534.87	29.01
	Total	610.50	481.97–734.91	11.20
Public sites combined	Weekend	974.36	448.21–1,675.91	35.85
	Weekday	683.27	314.30–1,134.22	30.11
	Total	1,657.63	1,480.78–1,839.58	5.54
Private beaches	Weekend	337.17	65.75–633.88	61.13
	Weekday	9.54	0.00–28.62	100.00
	Total	346.71	188.06–530.82	25.22
Total, all sites	Weekend	1,311.53	774.00–1,928.45	23.79
	Week day	692.81	415.68–1,004.57	22.31
Grand total		2,004.34	1,760.08–2,263.01	6.46

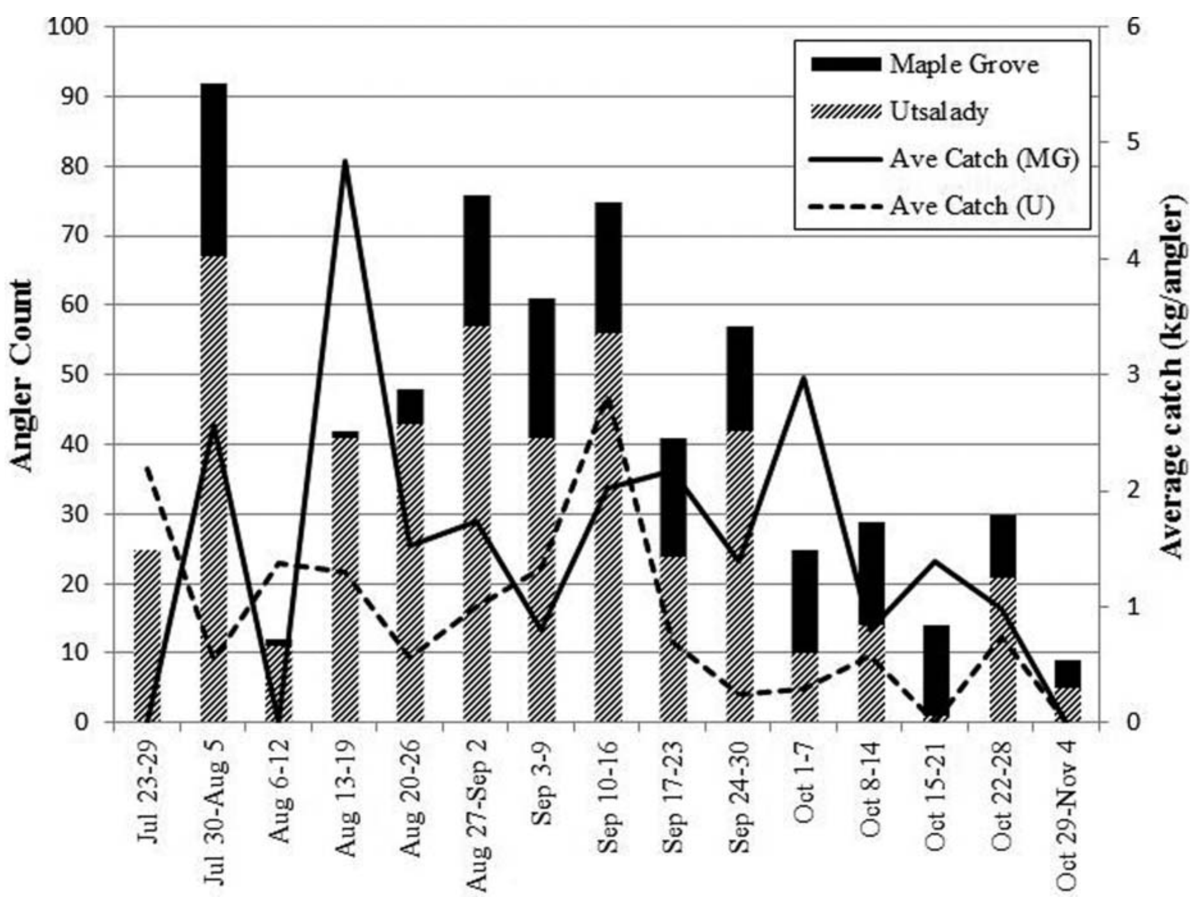

FIGURE 3. Surf Smelt catch (lines) and angler effort (bars) summarized by week from sampling conducted at public access sites (Maple Grove County Park [MG] and Utsalady County Park [U]) along northwest Camano Island. Fishing effort was typically higher at Utsalady County Park; daily average catch was often higher at Maple Grove County Park. Note that sampling ended on October 30, so the final week was partially sampled.

TABLE 2. Total estimated recreational fishing effort for Surf Smelt by site and day type (i.e., weekend versus weekday, as defined in Table 1) along northwest Camano Island. The fishery was closed on Wednesdays and Thursdays (CI = confidence interval; CV = coefficient of variation).

Site	Day type	Total trips	95% CI	CV (%)
Utsalady Park	Weekend	530.6	366.1–700.3	15.80
	Weekday	433.2	242.6–580.5	11.00
	Total	963.7	901.2–1,026.5	3.39
Maple Grove Park	Weekend	198.6	113.2–299.9	23.77
	Weekday	153.3	98.1–214.6	20.28
	Total	351.9	307.1–403.4	6.83
Public sites combined	Weekend	729.2	452.8–1,050.0	19.97
	Weekday	586.5	350.1–803.5	15.34
	Total	1,315.6	1,270.0–1,363.9	1.84
Private beaches	Weekend	278.3	133.6–445.2	35.20
	Weekday	82.0	0.00–213.2	77.98
	Total	360.3	310.5–416.6	7.91
Total, all sites	Weekend	1,007.4	771.7–1,259.3	12.29
	Weekday	668.5	501.4–855.7	13.48
Grand total		1,675.9	1,608.4–1,751.3	2.12

(weekend versus weekday) differences were not detected for start time or end time whether the two sites were pooled (start time: df = 1, $F = 0.05$, $P = 0.826$; end time: df = 1, $F = 3.27$, $P = 0.071$) or considered separately (start time: df = 1, $F = 0.30$, $P = 0.584$; end time: df = 1, $F = 0.31$, $P = 0.593$). This result indicates that day type was not a significant factor affecting fishing start time or end time. Anglers were adequately sampled by using the temporal window from

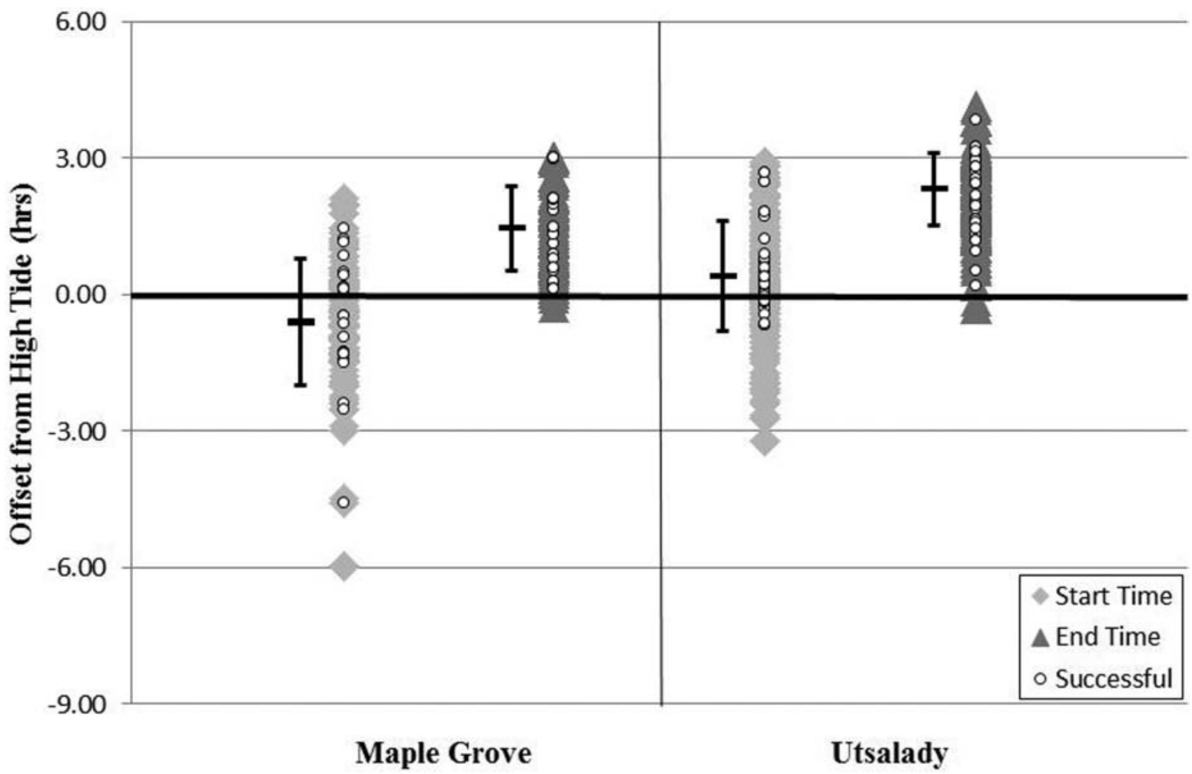

FIGURE 4. Surf Smelt fishing start and end times on a per-trip basis standardized to high tide (dark horizontal line) for each public access site (Maple Grove County Park and Utsalady County Park) along northwest Camano Island. Short bars to the left of each stacked series indicate the site-specific mean ± SD. Open circles represent successful trips.

TABLE 3. Pearson's product-moment correlation coefficients for environmental variables in relation to angler effort for Surf Smelt. Effort is summarized on a per-survey basis and was used as a proxy for Surf Smelt catch, as catch and effort were highly correlated.

Variable	Maple Grove Park effort	Utsalady Park effort	Combined effort
Tide height (ft)	0.402	0.558	0.449
High-tide time (hours)	0.195	0.522	0.36
Air temperature (°C)	0.142	0.400	0.282

approximately 2 h before high tide until 2.4 h after high tide at Maple Grove Park and from about 0.8 h before high tide until 3.1 h after high tide at Utsalady Park.

In many cases, especially at Utsalady Park, a significant social component for fishing start time was noted (an issue also observed by Wildermuth 1993 at Ross Point). Anglers stated that arriving at the park early gave them a chance to meet and mingle with friends and that they often did not catch fish until later in the day if at all. When only successful angling trips (Figure 4, open circles) were included in the analysis of the temporal sampling windows, differences remained between sites for start time (df = 1, $F = 14.48$, $P < 0.001$) and end time (df = 1, $F = 8.88$, $P = 0.004$), but the sampling window for Utsalady Park was shifted, requiring sampling to begin only 0.4 h before the high tide rather than 0.8 h before high tide.

When pooled by date across the time span of the study, angling effort was highly correlated (Pearson's product-moment correlation coefficient $\rho > |0.6|$) with catch ($\rho = 0.67$). Given this relationship, effort was used as a proxy for catch in all subsequent analyses of correlations with environmental variables. No single numeric environmental variable was highly correlated with angler effort at either site or when sites were combined (Table 3). The variable that had the strongest correlation with effort in any test was high-tide extent at Utsalady Park ($\rho = 0.558$), suggesting that anglers targeted higher high tides when possible. Because high-tide time shifts over the course of the year, it is unlikely that the relatively weak correlation found here ($\rho_{combined} = 0.360$) would hold for other seasons or other locations. Surf Smelt anglers fished regardless of air temperature, which spanned the range from 7.2°C to 32.2°C.

Categorical attributes of sampling events indicated that only site and sampling period could be used to describe patterns in angler effort (Table 4). Effort was substantially higher at Utsalady Park regardless of (1) the overall weather condition (overcast, raining, or sunny), (2) whether the day type was a weekend or weekday, and (3) the specific day of the week. Effort at Utsalady Park was generally higher than would be expected from its fishable area (i.e., just over twice as much fishable area as Maple Grove Park). These secondary variables had little influence on angler effort. Tukey's honestly significant difference test indicated that period-specific differences only occurred between period 2 (August 20–September 16) and period 4 (October 15–31), with effort per survey averaging 10.0 anglers during period 2 and 3.53 anglers during period 4.

Effort and Harvest at Private Beaches

Overall, 21 boat count surveys, each consisting of two replicates, were conducted in the area adjacent to the public access sites (Figure 2, cross-hatched area) between August 5 and October 30. Only 49 anglers were contacted during the surveys, but 26 of those anglers (53%) had Surf Smelt in possession at the time of contact, compared with 66.4% of anglers at the public access sites. Using the average weight determined for an individual Surf Smelt at the public access sites (32.5 g; see below) and expanding to Surf Smelt counts from the private beaches, the anglers on private beaches averaged a harvest of 0.57 kg, with some anglers catching up to 3.74 kg. No overharvest events were observed on private beaches, and the total observed harvest at private beaches was 27.69 kg over the course of the study.

The expanded estimate of harvest on private beaches for the entirety of the study was 347.04 kg, with over 84% of the harvest being taken on weekends during period 2 (August

TABLE 4. Results of two-way ANOVAs relating categorical survey attributes to angler effort for Surf Smelt along northwest Camano Island (SS = type III sum of squares). Site was used as a fixed factor in addition to the focal variable in each analysis. Effort is summarized on a per-survey basis and was used as a proxy for Surf Smelt catch, as catch and effort were highly correlated. *P*-values in bold italics were significant at the 0.05 level.

Source	df	SS	*F*-ratio	*P*-value
Site	1	495.05	8.71	***0.004***
Period	3	520.24	3.05	***0.033***
Site × period	3	301.55	1.77	0.159
Error	88	4,997.81		
Site	1	284.15	4.67	***0.033***
Weather condition	2	193.89	1.60	0.209
Site × weather condition	2	123.02	1.01	0.367
Error	90	5,468.76		
Site	1	707.46	11.25	<***0.001***
Day type	1	1.43	0.02	0.880
Site × day type	1	3.748	0.06	0.808
Error	92	5,785.60		
Site	1	822.38	13.70	<***0.001***
Day of week	4	430.23	1.79	0.138
Site × day of week	4	181.86	0.76	0.556
Error	86	5,163.71		

20–September 16; Table 1; Figure 5a). Expanded angler effort over the course of the study amounted to approximately 360 fishing trips on private beaches, with most of these trips occurring on weekends during period 2 (Table 2; Figure 5b).

Angler Behavior on Private Beaches

Assessment of angler behavior on private beaches was complicated by (1) low encounter rates, which produced numerous singularities in the data matrices; and (2) the fact that anglers were interviewed prior to finishing their fishing for the day. In total, 46 anglers were interviewed from August 5 through October 30, and all were encountered in the eastern two-thirds of the boat survey area (Figure 6). Although survey effort was evenly allocated between weekend and weekday fishing periods, 40 anglers (87.0%) were encountered on the weekend, and these anglers accounted for 97.8% of the observed harvest. Anglers on private beaches fished during all weather conditions and in air temperatures ranging from 15.6°C to 32.2°C. At the time of interview, anglers had fished anywhere from 5 to 300 min, and fishing start time ranged from over 3 h before high tide to 2 h after high tide (Figure 7). The range of start time offset relative to high tide was comparable to that observed at public access sites; as such, end time was assumed to be similar also. Anglers on private beaches successfully caught Surf Smelt across the entire range of start times observed in this study (Figure 7, open circles).

Overall Effort and Harvest Estimates

After expansion, an estimated total of 2,004.67 kg of Surf Smelt was harvested from public access points and private beaches combined from July 23 through October 30 (Table 1). The vast majority of this harvest (82.7%) was modeled to have come from public access points (Table 1), and a distinct peak was apparent on weekends during period 2 (August 20–September 19; Figure 5a). Overall effort for the season was modeled at approximately 1,676 angler trips (Table 2), with peak effort also occurring on weekends during period 2 (Figure 5b). Average catch on a studywide basis was 1.20 kg/angler.

Calculated CVs for overall harvest and effort were 6.46% and 2.12%, respectively (Tables 1, 2), well below the threshold of 15% set as a goal for this study, thus indicating that our study design can be effectively implemented. High variability in fish abundance—and therefore harvest—during some period × day type combinations resulted in CVs as high as 38.64% for subestimates of catch. Low angler encounter rates, especially on private beaches, led to CVs as high as 22.62% for effort subestimates. On average, the CV for any given period × day type combination was 22.53% for catch and 13.20% for effort.

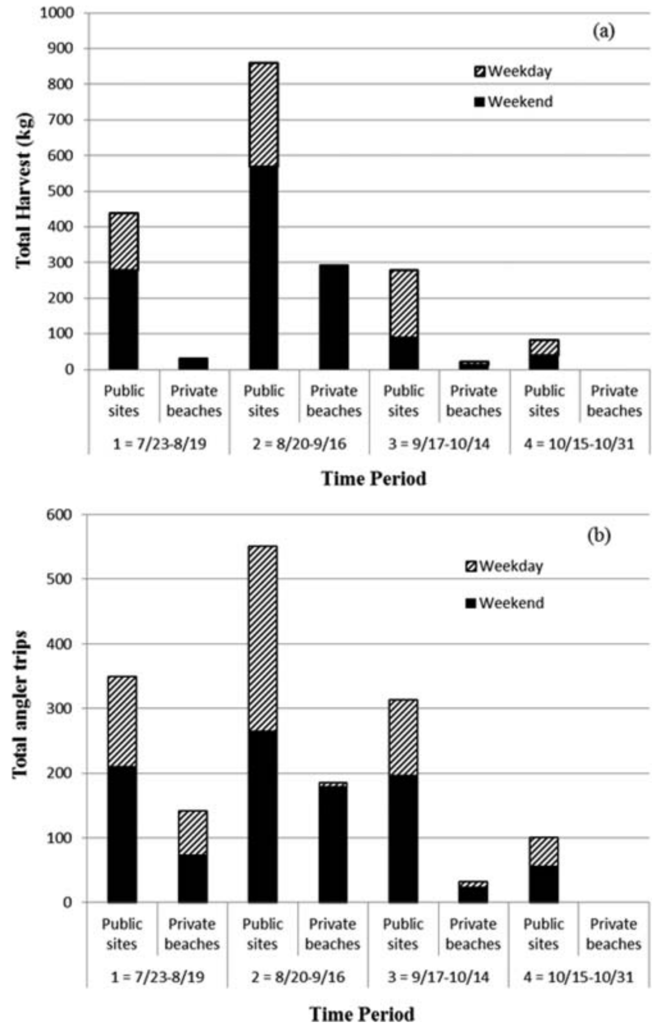

FIGURE 5. Total estimated **(a)** harvest of Surf Smelt and **(b)** fishing effort (angler trips) for Surf Smelt along northwest Camano Island by access type (public or private) and day type (weekday or weekend) within each of four time periods. Each time period was approximately 4 weeks, except for the final period (∼2 weeks).

Fish Size Distribution

The mean SL of all sampled Surf Smelt encountered in the study ($n = 1{,}358$) was 146.3 mm. Of the Surf Smelt for which sex was determined in the field (83% of specimens), 84% were male and 16% were female. On average, females were larger ($\bar{x} = 153.5$ mm) than males ($\bar{x} = 145.1$ mm), a trend that was also noted for Surf Smelt fisheries at Ross Point (Wildermuth 1993). Based on the conclusions of Penttila (1978), who interpreted a prominent length mode in the 130–155-mm range as representing 2-year-old fish, the length frequency distributions indicated that most of the Surf Smelt sampled in our study were 2 years old.

The average individual weight of Surf Smelt encountered in this study was 32.5 g; this weight was used to calculate harvest

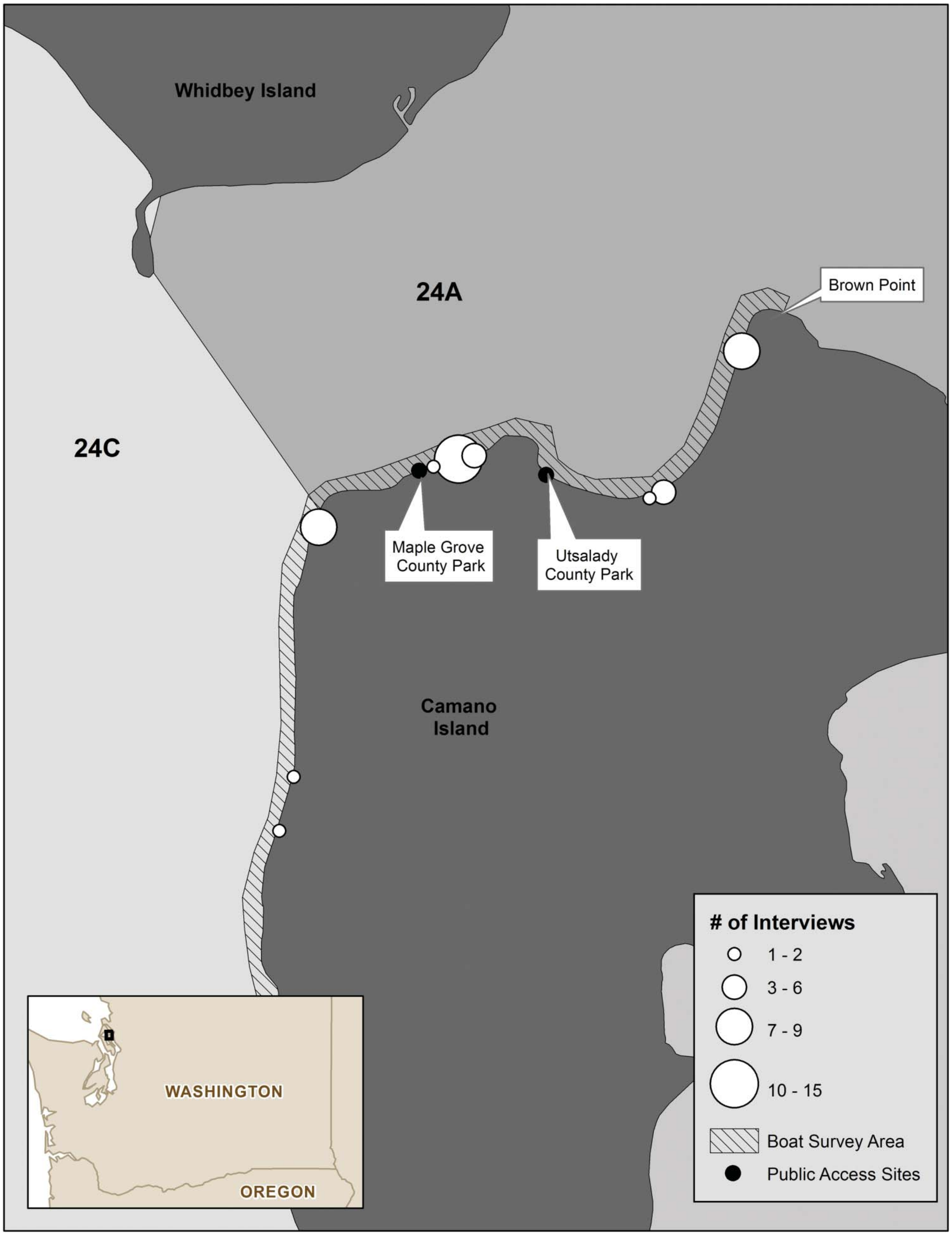

FIGURE 6. Private beach locations where anglers fishing for Surf Smelt were encountered over the course of the study. Survey effort continued to Onamac Point (Figure 2), but no anglers were encountered in the southernmost portion of the boat survey area.

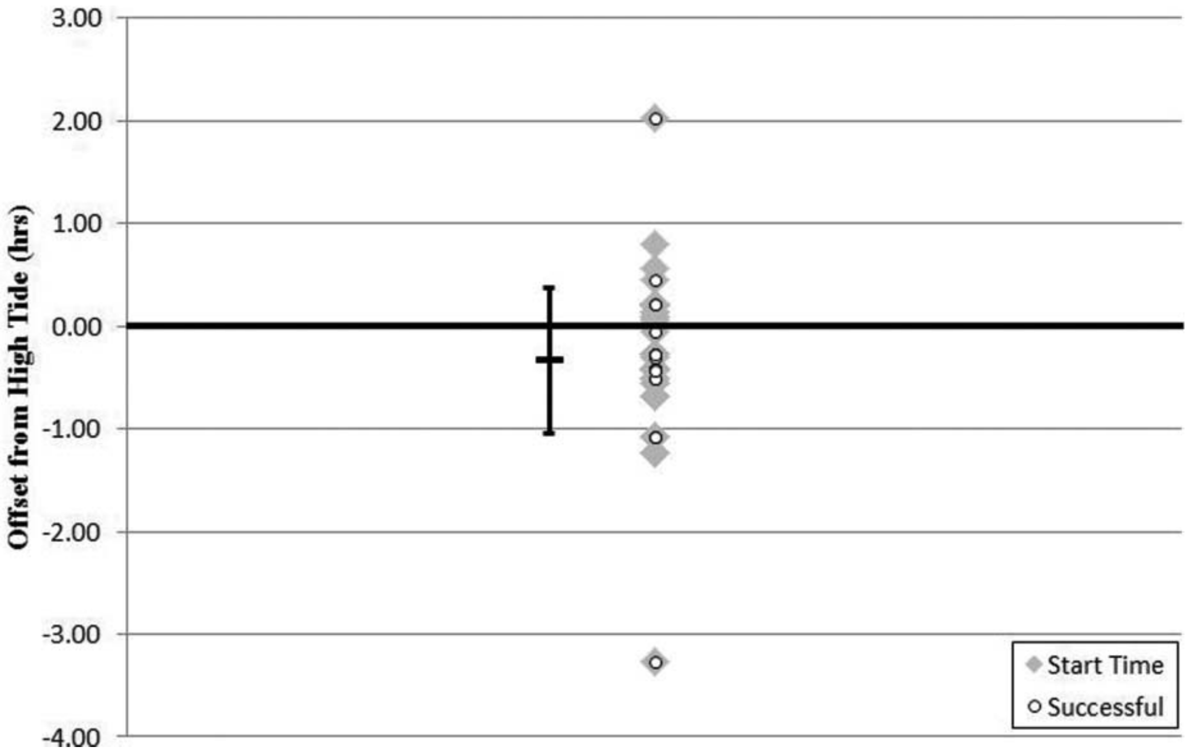

FIGURE 7. Surf Smelt fishing start times on a per-trip basis standardized to high tide (dark horizontal line) for private beaches along northwest Camano Island. The short bar to the left of the stacked series represents the mean ± SD. Open circles represent successful trips.

estimates for private beaches. Females weighed more on average (38.3 g) than males (31.5 g), which is not surprising given the variation in size between the sexes. When individual weight was regressed against time for each sex separately and for all Surf Smelt combined, no relationship was found that would indicate a directional trend over the course of the season.

DISCUSSION

This study effectively combined recreational angler interviews at public access sites and private beaches to generate fishing effort and Surf Smelt harvest estimates that were unbiased and that had low CVs. Sampling effort was more than adequate to meet predetermined CV goals, indicating that future efforts could incorporate a lower sampling frequency, especially at public access sites. Drawing on the experience of this study, if sampling effort is decreased to target a CV of 25% for the overall harvest estimate, we estimate that for twice the project cost, we could survey four public access points (or eight pairs of points like the pair used in this study) and adjacent private beaches. This survey design would be cost effective and would provide extensive data of immediate practical use for managing the Puget Sound Surf Smelt resource. Given a sufficient budget, this design could be extended to provide an unbiased estimate of Surf Smelt harvest by dip-net gear on a Puget Sound-wide basis.

For management purposes, overall annual recreational harvest of Surf Smelt in Puget Sound is assumed to be 45,060 kg, or approximately equivalent to the average commercial Surf Smelt catch in Puget Sound. In this study, we estimated that 2,004 kg (95% CI = 1,760–2,263 kg) of Surf Smelt were harvested by recreational anglers between Onamac Point and Brown Point on Camano Island between July 23 and October 31, 2012. This time frame covers the majority of the traditional fishing season at this popular, high-use Surf Smelt fishing location but almost certainly underestimates the total harvest because some fishing effort occurs outside of this peak period. Wildermuth (1993) used an access-point-only survey to quantify recreational Surf Smelt harvest at Ross Point, another high-use fishing site in Puget Sound, and estimated harvest at 3,490 kg in 1991. Angler interviews occurred during a 2-h window around high tide, but over 48% of observed fishing effort occurred outside of that sample frame (Wildermuth 1993). As such, actual harvest at Ross Point was likely substantially higher than the estimate provided by Wildermuth (1993). The sex and age composition of the catch, the size of fish encountered, and the individual weight of fish in this study were consistent with previous studies of Surf Smelt in Puget Sound (Penttila 1978; Hoffman and Palsson 1990; Wildermuth 1993).

Collectively, the results of the current study and the Wildermuth (1993) study indicate that recreational dip-net harvest of Surf Smelt at discrete high-use locations is on the order of hundreds to thousands of kilograms per season, although this is likely to vary substantially based on Surf Smelt abundance and fishing effort. If this Surf Smelt harvest level remains consistent at other popular fishing locations (i.e., a harvest of roughly 1,800 kg/season at each site), the potential exists for 10,000 kg or more to be harvested annually. Historically, WDFW documented 26 high-use sites in Puget Sound (Figure 1; Penttila 1992); however, the degree to which these sites are currently used is broadly unknown. Anecdotal knowledge suggests that harvest at many of these sites is significant only during years of high Surf Smelt abundance and high fishing interest, but the sites are not currently monitored. In addition, over 320 lineal kilometers of shoreline in Puget Sound are documented to be used by Surf Smelt for spawning (Penttila 2000, 2007), and much of this shoreline length has the potential to support private access dipnetting (Figure 1). Recreational harvest via dipnetting, the focus of this study, is not the only means by which to take Surf Smelt in Puget Sound; jigging is also allowed year-round from piers and boats and has supported a popular derby in the town of La Conner (Hoffman and Palsson 1990), though anecdotal data suggest that harvest and effort associated with this derby have waned in recent years. Hoffman and Palsson (1990) estimated that annual harvest during the derby was 6,439 kg in 1986. If (1) even a small fraction of private beaches are used in a pattern consistent with the observations from this study (i.e., 347 kg/season), (2) several currently unmonitored public access sites support harvest levels in the thousands of kilograms, and (3) the harvest at La Conner exceeds 3,175 kg (i.e., approximately half of historic levels), then there is a substantial chance that Surf Smelt recreational harvest exceeds the assumed level currently being used for resource management. This considerable knowledge gap can be addressed by the survey technique described herein.

In addition to demonstrating the validity and cost effectiveness of the survey design, this project elucidated patterns of recreational dipnetting effort in response to various environmental conditions, facilitating the development of future Surf Smelt fishery models. This study was the first of its kind in Puget Sound, despite longstanding Surf Smelt fisheries, and provides a starting point for estimating Puget Sound-wide recreational harvest based on sound science.

In the early 1990s, an effort was made to estimate recreational harvest of Surf Smelt at Ross Point, as noted above (Wildermuth 1993). Final estimates of harvest and effort from that study were complicated by a lack of dedicated funding for the work, which led to a 2-week "termination" of the study during the peak of the fishing season in 1992. Still, many of the behavioral patterns noted at the Ross Point location were similar to those we observed along north Camano Island. Specifically, in both locations, there was a social aspect to start time such that anglers were present on the beach well before the assumed "optimal" harvest window. Furthermore, results of our study and the Wildermuth (1993) study indicate that effort and harvest do not differ between weekdays and weekend days and that the majority of anglers successfully catch Surf Smelt.

Regardless of where they were encountered, successful recreational anglers surveyed in this study targeted an active fishing window based around the high tide. Surprisingly, the absolute height of the tide was not a significant factor dictating fishing effort, and neither was the time of day at which the high tide occurred, although a weak correlation suggested that they may be factors. If additional data can be obtained by sampling over a broader seasonal time frame in other high-use Surf Smelt fishing areas, it is possible that this weak relationship will develop into something substantive. Anecdotal information suggests that the time of day fishing occurred at Maple Grove Park was limited by local residents enforcing the dusk closure of the facility and strongly encouraging anglers to leave. This truncation of the available fishing time was not directly quantified but could have biased our results.

Beyond targeting a window around high tide, recreational fishers behaved differently at each of our public access sites and on private beaches. The fishable area at Utsalady Park was over twice the size of that at Maple Grove Park, and—in addition to the dusk closure issue mentioned above—there is also more parking at Utsalady Park. Together, these factors lead to more focused daytime effort at Maple Grove Park but substantially greater overall effort at Utsalady Park. Effort and harvest peaked in late August and early September at Utsalady Park but peaked a few weeks later at Maple Grove Park. The reason for this difference is unclear, but it is probably linked to Surf Smelt abundance in the vicinity of each site.

We have demonstrated that a combination of angler surveys at public access points and roving boat surveys of immediately adjacent private beaches can be successfully employed to estimate Surf Smelt harvest in a cost-effective manner. The harvest estimated for northwestern Camano Island, in combination with the few available indications of harvest in other parts of Puget Sound, suggests that the assumed Puget Sound-wide harvest rate for Surf Smelt may be inadequate to be considered "conservative." By selecting sampling locations based on historic fishery patterns, using the survey design described here, and tuning survey effort and timing based on in-depth knowledge of angler behavior, it is now possible to address Surf Smelt harvest by using sound science, a strategic goal of WDFW.

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