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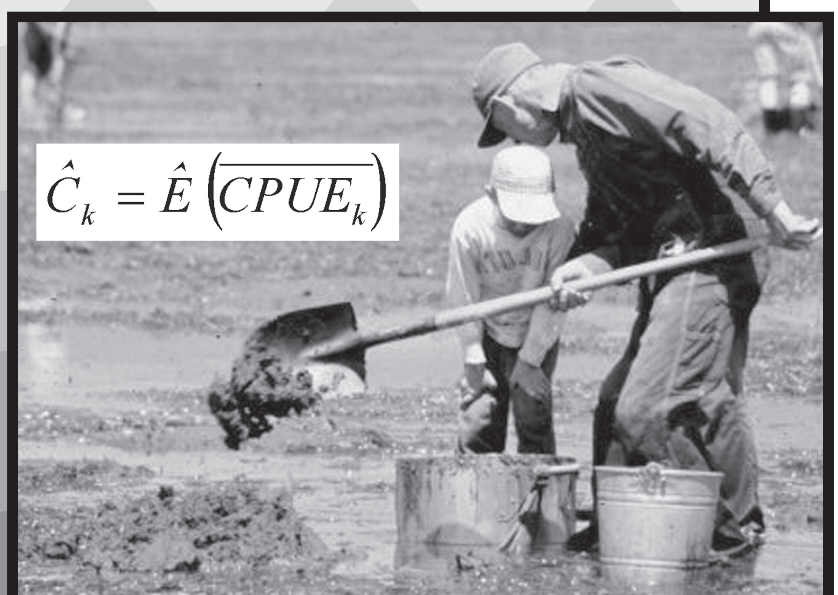
Estimating Recreational Clam and Oyster Harvest in Puget Sound

(Bivalve Regions 1, 5, 6, 7 and 8)



by Are Strom and Alex Bradbury

Washington Department of
FISH AND WILDLIFE
Fish Program
Fish Management Division

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Table of Contents

List of Figures

List of Tables

Introduction

The Washington Department of Fish & Wildlife (WDFW) has estimated recreational harvest of clams and oysters on Puget Sound public beaches since about 1970. The first systematic aerial surveys of sport harvesters occurred in 1969, and "ingress surveys" that recorded effort patterns throughout the course of a day began the following year. These early effort and harvest estimates involved a variety of survey methods, and tended to focus on a few of the most popular public shellfishing beaches.

More formal methods of estimating Puget Sound recreational clam and oyster harvest began following the 1994 Federal District Court order United States v. Washington (No. 9213, Sub-proceeding 89-3, Judge Edward Rafeedie), which reaffirmed the rights of treaty tribes to 50% of the harvestable surplus of shellfish. A method for estimating the recreational clam and oyster harvest was detailed in a 1997 appendix to the Bivalve Management Agreement (BMA) that described general management principles for state and tribal clam and oyster fisheries on public tidelands. The appendix remained an incomplete draft, however, and the BMA itself expired December 31, 2002. Revised harvest estimation methods for many areas of Puget Sound were described in appendices to the regional Bivalve Plans beginning in 2003 (Bradbury and Strom 2003).

Currently, annual estimates of the recreational catch of clams and oysters on public beaches are required by regional state-tribal Bivalve Plans. Under terms of these regional Plans, WDFW estimates recreational effort and catch on all actively managed public beaches, and total effort is reported on many passively managed beaches. (The distinction between active and passive management is described in all regional Bivalve Plans and the *Glossary* in this report). Besides meeting the requirements of federally mandated shellfish management plans, estimates of recreational effort and harvest are used to help recommend seasons and other regulations for the recreational fishery.

Harvest estimates are generated annually for Manila clams, native littleneck clams, butter clams, cockles, horse clams, geoducks, eastern softshell clams, and Pacific oysters. Harvest estimates are generated from two primary field activities: **(1)** aerial surveys, which are conducted from fixed-wing aircraft to estimate total effort (total harvester-days), and **(2)** creel surveys, which are conducted on selected beaches to determine catch per unit effort (CPUE, or pounds caught per harvester-day) by species. Additional sampling activities that have been conducted to refine harvest estimates include low tide counts, egress surveys, plus-tide surveys, and winter-harvest surveys.

In this report, we describe the methods currently used by WDFW to assess the recreational harvest of clams and oysters in Bivalve Regions 1 (Strait of Juan de Fuca), 5 (Admiralty Inlet), 6 (Central Puget Sound), 7 (South Puget Sound), and 8 (Hood Canal). All eight Bivalve Regions are shown in Figure 1. In Part I, we present the current harvest estimation methods contained in the appendices to all regional Bivalve Plans listed above. In Parts II through VI, we present data analyses that were used to design and justify the current harvest estimation methods. These include analyses of the flight route, the stratification of effort, the effort expansion factor, CPUE estimation, and the estimation of effort on "plus tides."

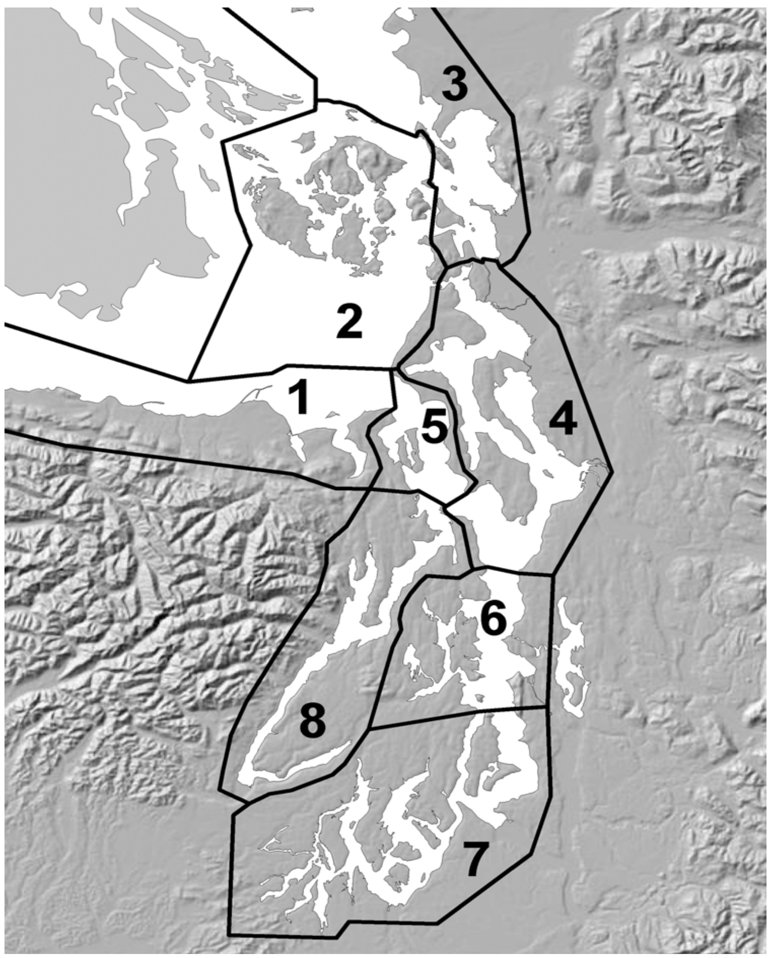

Figure 1. Bivalve Management Regions in Washington. This report primarily describes sport clam and oyster harvest estimation methods in Bivalve Regions 1, 5, 6, 7 and 8. An additional nine public beaches in Bivalve Region 4, located between Point No Point and Apple Cove Point are also included.

Part I: Current Harvest Estimation Methods

This section describes the methods currently used by WDFW to assess the recreational harvest of clams and oysters in Bivalve Regions 1 (Strait of Juan de Fuca), 5 (Admiralty Inlet), 6 (Central Puget Sound), 7 (South Puget Sound), and 8 (Hood Canal). With very minor edits, this section was taken from the appendix attached to the 2007 Bivalve Plans for the above Regions. The current sampling design and methods for creel, aerial and egress surveys are presented.

General Sampling Design

Recreational harvest (in pounds) on a given beach is estimated for each of the most important bivalve species as the product of total fishing effort (as harvester-days on the beach) and catch-per-unit-effort for that species (CPUE, as pounds per harvester-day on the beach).

Standardized sampling methods have been established to estimate effort and CPUE on public beaches. Sampling of recreational effort is stratified by tide height and day of the week (tide-day strata). These strata were selected based on analysis of flight data from 1994 to 2001 which showed that variation in fishing effort is related to differences in tide height and day of week (see Part III below). The three tide-day strata currently in use are described in Table 1. All available daylight tides from March through September < 2.0 ft are grouped according to tide-day strata, and sampling dates are randomly selected from available tides within each of the three strata.

Table 1. Tide-day sampling strata for recreational effort on intertidal beaches in Bivalve Regions 1, 5, 6, 7, 8 and a small section of 4. Extreme low tides = -2.0 ft and below; low tides = -0.1 to –1.9 ft; high tides = 0.0 to 1.9 ft. "Weekend" includes holidays.

Stratum Name	Description
ELOW	Weekend extreme low tides
LOW	Weekday extreme low tides, weekend low tides
HIGH	Weekday low tides, weekend and weekday high tides

Estimating total recreational harvest of clams on a beach involves the following sequence of steps:

1) An instantaneous count of recreational clam and oyster harvesters is obtained by flying over the beach close to low tide and counting harvesters. Each actively managed beach is flown roughly 45 times from March through September. Beaches with very short harvest seasons are surveyed on roughly 50% of the available tide days. Effort counts are stratified by the three tide-day strata shown in Table 1, and also by the seasonal

regulations on a beach (clams open/closed, oysters open/closed). Ground-based effort counts ("low tide counts") are used to augment the flyover counts.

2) The instantaneous count of harvesters for each survey day is expanded with an egress ratio to provide an estimate of the total number of harvesters on the beach for the entire day. An egress ratio is the expected proportion of harvesters present on a beach at the time during the low tide cycle when the instantaneous count was made from the air. Egress ratios are calculated based on a series of egress surveys during which observers counted all harvesters using the beach during the entire low tide cycle, and recorded the number of harvesters present at each half-hour interval during the cycle. Five egress models are currently used, depending on the beach where effort is being estimated and the tide-day stratum of the aerial survey.

3) An estimate of the mean number of harvesters per day is calculated for each of the three tide-day strata. These three estimates of mean daily effort are multiplied by the number of available clamming tides (days) within each of the three strata. These three products are summed, providing an estimate of the total number of harvesters using the beach from March through September (except on "plus tides").

4) An estimate of the number of harvesters using the beach on "plus tides" (those tides $\geq$ 2.0 and < 4.0 ft) is added to the effort estimate calculated in Step 3 above. Effort on plus tides is assumed to be 16.0% of the unstratified mean daily effort on all surveyed tides on the beach. This assumption is based on an analysis of flight data collected during plus tides in 1993 and 1994.

5) On certain beaches, where winter harvest has been observed in the past, an estimate of the number of harvesters using the beach during the winter months (October through February) is added to the effort estimate. Effort during the winter on these beaches is assumed to be 5.0% of the total effort from March through September (including plus-tide effort).

6) Catch per unit effort (CPUE) is estimated for each species on the beach from creel surveys. During each creel survey, all (or most of) the harvesters leaving the beach are interviewed, and their catch is sorted by species and weighed. For each creel survey, the daily CPUE is the average number of pounds (by species) taken per harvester.

7) An estimate of the average season-long CPUE on the beach (again, for each species) is made by averaging all the creel survey data from the most recent three years of data available for that beach.

8) An estimate of total harvest on the beach (by species) is calculated by multiplying total estimated effort on the beach (including plus-tides and winter use, if applicable) by mean CPUE for the species.

Creel Surveys

Creel surveys are conducted for a 4-hr period straddling the local time of low tide. Only harvesters who have completed their day's harvest are interviewed, and whenever possible, all harvesters exiting the beach during this 4-hr time period are interviewed. The total weight and number of each species harvested is recorded. The number of harvesters per party is also recorded.

The daily *CPUE* for each species on a beach is estimated for each creel survey day by dividing the total daily catch (pounds per species for clams, or number of oysters) by the total number of harvesters interviewed:

$$CPUE_d = \frac{\sum_{i=1}^{n} catch_{i,d}}{\sum_{i=1}^{n} harvester_{i,d}} \qquad (1)$$

where

$CPUE_d$ = the daily *CPUE* on day *d*
$catch_{i,d}$ = the catch (pounds for clams, numbers for oysters) by the *i*th harvester on day *d*
$harvester_{i,d}$ = the *i*th harvester interviewed on day *d*
n = the total number of harvesters interviewed on day *d*

A separate $CPUE_d$ is calculated for each species (Manila clams, native littlenecks, cockles, butter clams, geoducks, etc.). If broken clams are present in the creel, they are counted but not weighed; the weight of broken clams is estimated based on the average weight of unbroken clams of the same species in the creel. Since all interviews are conducted at the end of harvesters' trips, and since a large percentage of all the day's harvesters are likely to be interviewed during a sample day (roughly 90%, Strom and Bradbury 2006), $CPUE_d$ is assumed to be a creel census observation of the day's CPUE that is without variance.

The mean season-long *CPUE* for each species on a beach is estimated as a three-year running mean, averaging all the estimates of $CPUE_d$ for the previous three years in which creel surveys were performed on the beach:

$$\overline{CPUE} = \frac{\sum_{t=1}^{3} CPUE_{d,t}}{\sum_{t=1}^{3} n_t} \qquad (2)$$

where

$\overline{CPUE}$ = the mean season-long *CPUE*

$CPUE_{d,t}$ = the daily *CPUE* on day *d* of year *t*

n_t = the number of days the beach was sampled by creel survey in year *t*

Separate estimates of $\overline{CPUE}$ are calculated for each species within the open and closed seasons on a beach (i.e., clams open/closed, oysters open/closed). For situations when the clam season is closed but the oyster season remains open, $\overline{CPUE}$ is calculated as the average of all available closed/open creel surveys conducted over the past six years, rather than just the most recent three years as above. This modification is required to maintain acceptable creel survey sample size. For obvious reasons, creel surveys are not conducted on a beach when it is closed to *both* clams and oysters. The default $\overline{CPUE}$ assumed during periods when a beach is closed for both clams and oysters is the open-season $\overline{CPUE}$.

The variance of the mean season-long *CPUE* is estimated as:

$$Var\left(\overline{CPUE}\right) = \frac{\left[\sum_{n=1}^{s}\left(CPUE_d - \overline{CPUE}\right)^2 \Big/ n-1\right]}{n} \qquad (3)$$

where *n* = 1 to *s* surveys over the past three creel-survey years, which are averaged.

Aerial Surveys

Observers in fixed-wing aircraft monitor fishing effort on public beaches along the shorelines of the Strait of Juan de Fuca, Puget Sound, and Hood Canal, targeting areas where significant recreational harvest is known to occur. A single flight route has been developed to encompass all public beaches in Bivalve Regions 1, 5, 6, 7 and 8 that are important from a management perspective. The route was designed to ensure that most beaches would be flown over close to the time of local low tide. Flight counts consistently occur within one hour of local low tide except at Oakland Bay and Dyes Inlet. Approximately 92% of all flight counts in 2004 and 2005 occurred within 30 minutes of the local low tide when Oakland Bay and Dyes Inlet beaches were not considered (see Part IV below). The route starts at Sequim Bay and follows the falling tide as it progresses towards southern Puget Sound (Figure 2). Barring adverse wind conditions, the survey starts at Sequim Bay exactly at local low tide and ends at Frye Cove in southern Puget Sound two hours later, again close to the local low tide.

Flight surveys provide an instantaneous count of all harvesters on a beach at a given moment during the tide cycle. Harvesters are counted from fixed wing airplanes flying at 70 - 120 knots at an altitude of 500 - 700 ft. The distance flown from the shore is approximately 200 ft from the line of low water, but varies with the width of the intertidal zone to ensure complete coverage of the tidelands and nearshore area.

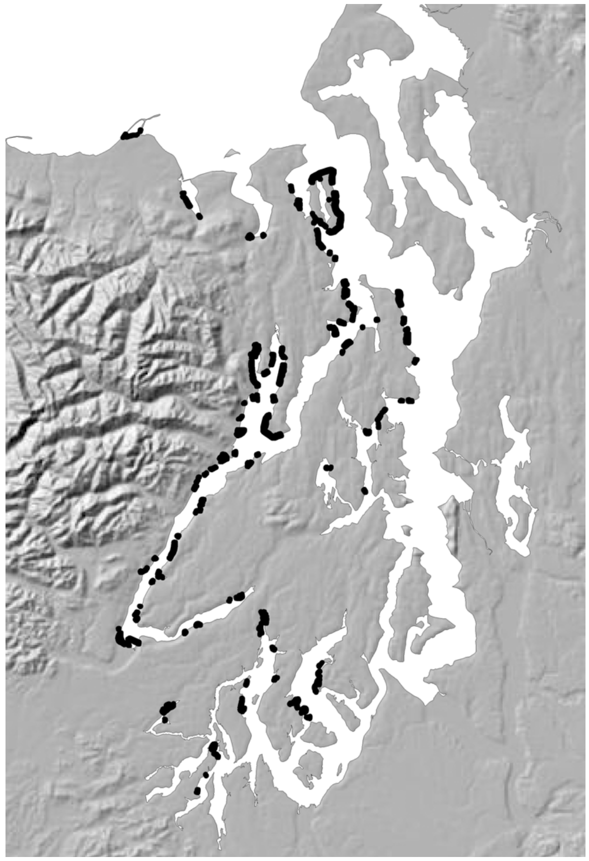

Figure 2. Public beaches (bold black outlines) covered on the flight route in Bivalve Regions 1, 5, 6, 7, 8, and a small portion of Bivalve Region 4. The route starts at Sequim Bay in the eastern Strait of Juan de Fuca and ends at Frye Cove in southern Puget Sound. Ground-based effort counts are conducted at beaches in the Dungeness Spit area, located in the northwest corner of this map.

Only those people actively engaged in clam or oyster harvesting, or those clearly equipped to do so, are counted during aerial surveys. This includes people with shovels and buckets leaving or entering the beach. Clam and oyster harvesters are not separated in the flight counts because the two user types cannot be differentiated during flyovers; it is also common for a harvester to switch at some point in the day from taking oysters to clams, or vice versa. The number and type of harvesters on each beach is recorded directly on computer generated flight maps, along with the time the count was made. Commercial harvesters, tribal harvesters and WDFW personnel are counted and labeled separately on the maps to ensure that individuals participating in these activities are distinguished from recreational harvesters. The summation process only includes individuals whom the surveyor determines to be actively engaged in recreational clam or oyster harvesting.

Flight surveys are assigned to one of the three tide-day strata described in Table 1 above. These strata are based on a comprehensive analysis of all flight data and low tide count data from 1994 through 2001. Cluster analysis, Monte Carlo simulations, and analysis of variance (ANOVA) concluded that the three tide-day strata shown in Table 1 produce estimates of total effort with equal or higher precision than the former twelve strata scheme (see Part III below). Flight dates are randomly assigned among the three strata based on an optimum allocation formula (Thompson 1992) and on the number of days available each month within the strata designations. More flights are scheduled during the months May-July simply because more tide-days are available within each stratum during this period.

Flight counts are also post-stratified by seasonal regulations on each beach (clams open/closed, oysters open/closed). Harvester counts are made on actively managed beaches even during periods when they are closed to both clam and oyster harvest by WDFW regulations (i.e., the clams closed/oysters closed stratum). Total effort estimates therefore include illegal sport effort where it has been observed during aerial surveys.

Low Tide Counts

Low tide counts are used to supplement aerial survey data in cases where additional data are needed to estimate harvest rates. Insufficient sample sizes in flight counts can occur when the airspace above a beach is temporarily restricted, when seasons are very short, when seasons end early in the year, or when very high variance in historical counts on a beach dictates that increased sampling is needed. Low tide counts are conducted at the time of the local low tide by a ground observer (e.g., park ranger, WDFW surveyor) who records the data on a computer-generated map of the beach area. Low tide counts are recorded in the same manner as flight counts, with separate designations for recreational, tribal and commercial harvesters.

Effort Expansion Factors (Egress Ratios)

The count of harvesters obtained from flights or low-tide counts is obviously an instantaneous count, and it is not likely to represent the total number of harvesters using the beach over the entire day. An expansion factor is therefore used to generate an estimate of total all-day effort from each instantaneous effort count.

Effort expansion factors are based on egress models that relate the number of harvesters present at any one instant during the tide cycle to total all-day effort. These egress models were derived from 696 individual egress surveys conducted on 39 public beaches, spanning a time period from 1989 to 2005. These egress surveys were conducted within a 6-hr time block centered on the time of local low tide. The total number of shellfish harvesters leaving ("egressing") the beach during the 6-hr time block was recorded, along with instantaneous counts of harvesters present on the beach at half-hour intervals ("activity counts"). Any harvesters still present on the beach when the survey ended were added to the total harvester egress count. An egress ratio for any given half-hour increment was calculated as:

$$R_t = \frac{H_t}{H_s} \tag{4}$$

where

R_t = the egress ratio at time t (the proportion of all-day effort present at time t on the survey day)

t = the time (in minutes) relative to local low tide (e.g., at local low tide, $t = 0$; one half hour later, $t = 30$; one hour prior to local low tide, $t = -60$)

H_s = the total number of harvesters observed leaving ("egressing") the beach during the 6-hr time interval spanning local low tide, including any harvesters still present when the survey ended.

H_t = the total number of harvesters observed on the beach at time t (the "activity count" at time t)

Data from the 696 egress surveys were analyzed for significant differences in harvester behavior (i.e., patterns in the egress ratios) among beaches and among the three tide-day strata. Five egress models (Table 2, Figure 3) were defined: (1) two models for Normal beaches, which comprise 130 of the 140 public beaches currently observed during flights. One of the two models for Normal beaches expands harvester counts observed during the ELOW tide-day stratum (i.e., during weekend/holiday extreme low tides); the second model expands counts on Normal beaches made during the other two tide-day strata (collectively called the "non-ELOW" strata), (2) a model for six Early Peak beaches (Potlatch State Park, Potlatch DNR, Lilliwaup State Park, Eagle Creek, Fort Flagler State Park, and P.T. Ship Canal East), where the peak of all-day harvester effort occurs roughly 30 minutes prior to low tide, and is significantly higher than the peak effort on Normal beaches during non-ELOW tides, (3) a model for three High Peak beaches (Dosewallips State Park, Duckabush, and Rendsland Creek), where the peak of all-day harvester effort occurs near low tide but is significantly higher than the peak effort on Normal beaches, and (4) a model for Twanoh State Park, where the peak effort is significantly lower than on Normal beaches and occurs somewhat earlier.

Table 2. Descriptive statistics for the five current egress models. Values shown for each half-hour time-interval include the mean egress ratio ($\overline{R_t}$), standard deviation of the data (SD), standard error of the mean (SE), relative standard error (RSE), and sample size (N).

	Normal, non-ELOW					*Normal, ELOW*				
Time Interval	R_t	**SD**	**SE**	**RSE**	**N**	R_t	**SD**	**SE**	**RSE**	**N**
-180	0.034	0.125	0.0113	0.335	123	0.038	0.058	0.0105	0.278	31
-150	0.050	0.132	0.0119	0.240	123	0.055	0.075	0.0135	0.246	31
-120	0.084	0.152	0.0078	0.093	380	0.095	0.101	0.0154	0.162	43
-90	0.140	0.181	0.0093	0.066	380	0.151	0.113	0.0173	0.114	43
-60	0.189	0.205	0.0105	0.056	379	0.260	0.174	0.0265	0.102	43
-30	0.245	0.226	0.0116	0.047	377	0.312	0.159	0.0242	0.078	43
0	0.277	0.250	0.0129	0.046	377	0.373	0.211	0.0322	0.086	43
30	0.248	0.240	0.0124	0.050	378	0.353	0.215	0.0327	0.093	43
60	0.177	0.211	0.0109	0.062	373	0.288	0.185	0.0286	0.099	42
90	0.127	0.190	0.0098	0.077	378	0.181	0.179	0.0273	0.151	43
120	0.071	0.144	0.0074	0.105	379	0.134	0.157	0.0240	0.179	43
150	0.075	0.171	0.0154	0.205	123	0.056	0.064	0.0115	0.206	31
180	0.035	0.091	0.0082	0.233	123	0.035	0.050	0.0090	0.255	31

	Early Peak					*High Peak*				
Time Interval	R_t	**SD**	**SE**	**RSE**	**N**	R_t	**SD**	**SE**	**RSE**	**N**
-180	0.040	0.068	0.0092	0.230	55	0.036	0.096	0.0169	0.467	32
-150	0.068	0.097	0.0131	0.194	55	0.056	0.114	0.0202	0.357	32
-120	0.093	0.160	0.0136	0.146	138	0.093	0.145	0.0174	0.187	70
-90	0.169	0.213	0.0181	0.107	139	0.176	0.224	0.0268	0.152	70
-60	0.296	0.261	0.0221	0.075	139	0.270	0.229	0.0278	0.103	68
-30	0.370	0.267	0.0228	0.062	138	0.386	0.258	0.0312	0.081	68
0	0.296	0.260	0.0220	0.074	139	0.415	0.260	0.0313	0.076	69
30	0.192	0.216	0.0184	0.096	137	0.347	0.264	0.0315	0.091	70
60	0.109	0.160	0.0136	0.124	139	0.240	0.244	0.0294	0.123	69
90	0.063	0.126	0.0107	0.169	138	0.110	0.156	0.0187	0.170	70
120	0.068	0.154	0.0131	0.193	139	0.051	0.093	0.0111	0.215	70
150	0.060	0.131	0.0176	0.296	55	0.035	0.069	0.0123	0.350	32
180	0.025	0.104	0.0140	0.571	55	0.021	0.069	0.0123	0.588	32

	Twanoh State Park				
Time Interval	R_t	**SD**	**SE**	**RSE**	**N**
-180	0.025	0.063	0.009	0.363	48
-150	0.041	0.076	0.011	0.268	48
-120	0.072	0.111	0.014	0.191	64
-90	0.103	0.109	0.014	0.132	64
-60	0.156	0.129	0.016	0.103	64
-30	0.227	0.178	0.022	0.098	64
0	0.222	0.191	0.024	0.108	64
30	0.182	0.133	0.017	0.091	64
60	0.155	0.132	0.016	0.106	64
90	0.092	0.087	0.011	0.119	64
120	0.104	0.133	0.017	0.159	64
150	0.060	0.073	0.011	0.177	48
180	0.035	0.072	0.010	0.296	48

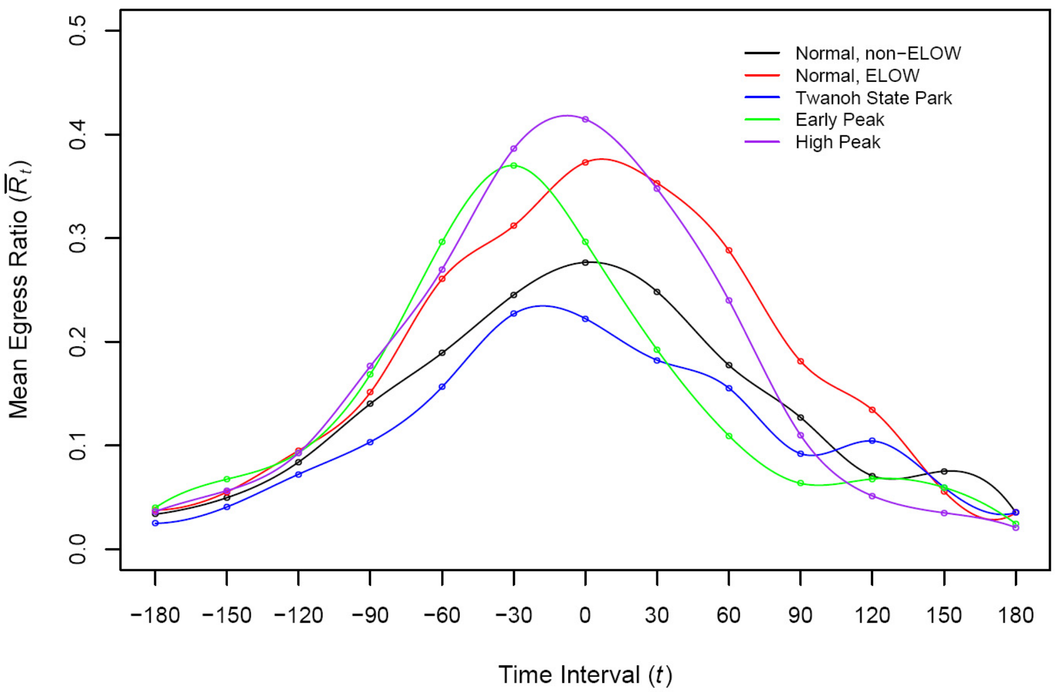

Figure 3. The five egress models used to expand instantaneous harvester counts into estimates of "all day" effort. Time intervals are shown as minutes before and after local low tide (t = 0). All values between half-hour intervals were interpolated with a cubic spline function.

Part IV of this report provides a detailed description of the egress analysis and the effort expansion factors and egress models currently used.

For each model and time interval, the mean egress ratio for any given half-hour increment *t* was calculated as:

$$\overline{R}_t = \frac{1}{n}\sum_{i=1}^{n} R_t \qquad (5)$$

where

$\overline{R}_t$ = the mean egress ratio (i.e., the proportion of all-day effort expected at time *t*)

n = the number of estimates of R_t available at time *t* (for most *t*, this is equal to the total number of egress surveys)

Model points were interpolated for times between the observed half-hour time intervals using a cubic spline function . This "smoothed" the egress curves and allowed egress ratios to be calculated for any even-minute time interval during the low tide cycle.

Examples: On a Normal beach within the non-ELOW stratum at the time of local low tide, the mean egress ratio ($\overline{R}_0$, from Table 2) is 0.277. On an Early Peak beach 30 minutes prior to local low tide, the mean egress ratio ($\overline{R}_{-30}$, from Table 2) is 0.370.

Plus Tide Effort Estimates

Mean daily effort on plus tides (tides ≥ 2.0 ft and < 4.0 ft) is estimated for each beach as 16% of the unstratified mean daily effort on the beach (see Part V of this report). This product is then multiplied by the number of available plus tide days to estimate the total effort on plus tides:

$$\hat{E}_{plustides} = 0.16\left(\frac{1}{n}\sum_{1}^{n} E_d\right)D_{plustides} \tag{6}$$

where

n = the total number of effort samples (days) in all three tide-day strata
E_d = the estimated total number of harvesters using the beach on day d
$D_{plustides}$ = the total number of available plus tide harvest days

Effort on plus tides is added to the total effort estimate ($\hat{E}total$) on tides $\geq$ 2.0 ft for an estimate of total effort on all clamming tides. The 16% figure is based on an analysis of effort data collected on plus tides flight surveys in 1993 and 1994.

Winter Effort Estimates

Low tides occur primarily during daylight hours from March through September, but during the rest of the year, low tides suitable for shellfish harvest occur mostly at night. Surveys conducted by WDFW from November 1994 through February 1995 confirmed that wintertime recreational harvest occurred on 24 of the beaches included on the 2002 flight route (Figure 1).

These surveys indicated that winter harvest represents a very small proportion of the overall yearlong harvest. Based on these data, winter effort is estimated as 5% of the March – September total effort, including plus-tide effort (Bradbury and Strom 2003):

$$\hat{E}_{winter} = 0.05\left(\hat{E}_{total} + \hat{E}_{plustides}\right) \tag{7}$$

This effort is added to the total effort estimate for all clamming tides for an estimate of year-long effort on a beach.

Estimation of Total Effort on a Beach

The estimation of total recreational effort on a beach (harvester days) is described in the following six calculation steps. Effort sampling is stratified by three tide-day strata (ELOW, LOW and HIGH), and effort estimates are also post-stratified by seasonal regulations on each beach (clams open/closed, oysters open/closed). Effort is therefore separately estimated for periods when a beach may be closed to clamming, closed to oystering, and closed to the harvest of *both* clams and oysters. Total effort estimates on a beach are the sum of these post-stratified time periods, and therefore include effort estimated during closed-seasons as well as during open-seasons. In order to simplify the following equations, however, we have omitted mention of this post-stratification by seasonal regulation.

Step 1: Estimation of daily (all-day) effort on a sample day

All-day recreational effort (total number of harvesters) on a beach on sample day d within tide-day stratum h is estimated as:

$$\hat{E}_{d,h} = E_t / \overline{R}_t \qquad (8)$$

where

$\hat{E}_{d,h}$ = the estimated total number of harvesters using the beach all day on day d within stratum h

E_t = the observed instantaneous count of harvesters on the beach at time t on day d

$\overline{R}_t$ = the mean proportion of all-day effort expected at time t (obtained from Table 2, using the appropriate egress model; for example, $\overline{R}_t$ for a Normal beach sampled during the LOW tide-day stratum would be obtained using the Normal, non-ELOW egress model shown in Table 2. Values of $\overline{R}_t$ for all time intervals between even half-hours are given in Tables 11-15.

Example: If the observed instantaneous count of harvesters on a Normal beach during a non-ELOW sampling day at 30 minutes past local low tide is 23 harvesters, $\overline{R}_{30}$ (from Table 2) = 0.248, and $\hat{E}_{d,h}$ = 23 / 0.248 = 92.74 harvesters.

Approximate variance of the estimated all-day effort on day d within tide-day stratum h is calculated using the delta method as:

$$Var\left(\hat{E}_{d,h}\right) = Var\left(\overline{R}_t\right) \times \left[\left(E_t^2\right) / \left(\overline{R}_t^4\right)\right] \qquad (9)$$

where

$Var\left(\hat{E}_{d,h}\right)$ = the variance of the estimated all-day effort on day d within stratum h

$Var\left(\overline{R}_t\right)$ = the variance of the mean proportion of all-day effort at time t (i.e., $\overline{R}_t$). This quantity can be calculated for each of the five egress models from Table 2 as: $Var\left(\overline{R}_t\right)$ = SE^2, where SE is the tabled standard error of $\overline{R}_t$ for time interval t.

Step 2: Estimation of mean daily effort within a tide-day stratum

The mean daily effort on a beach within each of the three tide-day strata is given by:

$$\overline{E}_h = \frac{1}{d_h}\sum_{d=1}^{d_h}\hat{E}_{d,h} \tag{10}$$

where

$\overline{E_h}$ = the mean daily effort in tide-day stratum h

d_h = the number of sampled days in tide-day stratum h

$\hat{E}_{d,h}$ = the estimated total number of harvesters using the beach on day d in tide-day stratum h.

The variance of the mean daily effort within any tide-day stratum is estimated with a two-stage variance formula (Cochran 1977). The first component of the variance is the variation *between* sample days, and the second component of variance is the variation *within* sample days (i.e., the egress model variation for each value of $\overline{R}_t$).

$$Var(\overline{E_h}) = \left[\frac{D_h - d_h}{D_h}\right]\frac{s_h^2}{d_h} + \left[\sum_{d=1}^{d_h} Var(\hat{E}_{d,h}) \Big/ \left(D_h d_h\right)\right] \tag{11}$$

where

D_h = the total number of available harvest days (daylight tides) within tide-day stratum h

d_h = the number of sample days (i.e., flights or ground-based low tide counts) conducted on the beach within stratum h

and the between-day variance for stratum h is:

$$s_h^2 = \frac{\sum_{d=1}^{d_h}\left(\hat{E}_{d,h} - \overline{E}_h\right)^2}{d_h - 1} \tag{12}$$

Equation 11 incorporates the finite population correction factor ($D_h - d_h / D_h$) because we tend to sample a significantly large proportion of days from a finite population of harvestable days. In such instances, the finite population correction factor may have an appreciable effect in reducing the variance of estimated mean daily effort.

Step 3: Estimation of total season-long effort within a tide-day stratum

The total season-long effort within a tide-day stratum is the product of the mean daily effort for that stratum (calculated in Step 2 above) and the total number of harvesting days available within that stratum:

$$\hat{E}total_h = D_h \overline{E}_h \tag{13}$$

where

$\hat{E}total_h$ = the estimated total season-long effort (number of harvester-days) within tide-day stratum h

D_h = the total number of available harvest days (daylight tides) within tide-day stratum h

The variance of the total estimated season-long effort on a beach within any tide-day stratum is estimated with a two-stage variance formula (Cochran 1977). The first component of the variance is the variation *between* sample days, and the second component of variance is the variation *within* sample days (i.e., the egress model variation for each value of $\overline{R}_t$).

$$Var(\hat{E}total_h) = D_h^2 \left[\frac{D_h - d_h}{D_h}\right]\frac{s_h^2}{d_h} + \left[\frac{D_h}{d_h}\sum_{d=1}^{d_h} Var(\hat{E}_{d,h})\right] \tag{14}$$

Equation 14 incorporates the finite population correction factor ($D_h - d_h / D_h$) because we tend to sample a significantly large proportion of days from a finite population of harvestable days. In such instances, the finite population correction factor may have an appreciable effect in reducing the variance of total estimated effort.

Step 4: Estimation of total effort on a beach (all strata)

The total season-long effort on a beach is estimated as the sum of the effort estimates from the three tide-day strata (ELOW, HIGH and LOW) as calculated using Equation 11 above:

$$\hat{E}total = \sum_{h=1}^{3} \hat{E}total_h \tag{15}$$

or, equivalently:

$$\hat{E}total = \hat{E}total_{ELOW} + \hat{E}total_{HIGH} + \hat{E}total_{LOW} \tag{16}$$

where

$\hat{E}total =$ the total estimated season-long effort (harvester-days)

$\hat{E}total_h =$ the total estimated season-long effort (harvester-days) within tide-day stratum h

The variance of the estimated total effort is the sum of the variance estimates from the three tide-day strata as calculated using Equation 14 above:

$$Var(\hat{E}total) = Var(\hat{E}total_{ELOW}) + Var(\hat{E}total_{HIGH}) + Var(\hat{E}total_{LOW}) \qquad (17)$$

Step 5: Estimation of a 95% confidence interval on the estimation of total effort

The standard error (SE) of the total season-long effort on a beach $(\hat{E}total)$ is given by:

$$\mathrm{SE}(\hat{E}total) = \sqrt{Var(\hat{E}total)} \qquad (18)$$

The approximate 95% confidence interval for the estimate of total season-long effort is computed by multiplying the SE by the appropriate tabled *t*-value:

$$\hat{E}total \pm t_{0.05,df} \sqrt{Var(\hat{E}total)} \qquad (19)$$

where *t* is the upper α/2 point of Student's *t* distribution with *df* degrees of freedom computed with the Satterthwaite (1946) approximation:

$$df = \left(\sum_{h=1}^{3} a_h s_h^2 \right)^2 \Bigg/ \left(\sum_{h=1}^{3} \left(a_h s_h^2 \right)^2 / \left(d_h - 1 \right) \right) \qquad (20)$$

where

$a_h = D_h (D_h - d_h) / d_h$

$s_h^2 =$ the between-day variance as estimated in Equation 12 above.

Step 6: Addition of plus-tide and winter effort estimates

The final step in estimating effort on a beach is to add the estimates of effort during plus tides (from Equation 6 above) and, on certain beaches, estimated effort during the winter months (from Equation 7 above):

$$\hat{E}grandtotal = \hat{E}total + \hat{E}_{plustides} + \hat{E}_{winter} \quad (21)$$

For the sake of convenience, the variance of $\hat{E}grandtotal$ is assumed to be equal to $Var(\hat{E}total)$. Estimates of variance are not available for plus-tide effort and winter effort, and both quantities are very small in relation to $\hat{E}grandtotal$.

Estimation of Within-Stratum Harvest on a Beach

Harvest for each species is estimated separately within each of the three tide-day strata, as well as for plus tides and winter (if applicable).

Mean daily harvest of species *k* within stratum *h* is estimated as:

$$\overline{C_{h,k}} = \left(\overline{CPUE_k}\right)\left(\overline{E_h}\right) \quad (22)$$

where

$\overline{C_{h,k}}$ = the mean daily harvest (total pounds per day) of species *k* within tide-day stratum *h*

$\overline{CPUE_k}$ = mean season-long CPUE (pounds per harvester) of species *k* from Equation 2

$\overline{E_h}$ = mean daily effort (harvesters per day) within tide-day stratum *h* from Equation 10

The variance of the estimated mean daily harvest within stratum *h* is estimated for each species *k* as a variance of products (Goodman 1960):

$$Var\left(\overline{C_{h,k}}\right) = \overline{CPUE_k}^2\left[Var\left(\overline{E_h}\right)\right] + \overline{E_h}^2\left[Var\left(\overline{CPUE_k}\right)\right] - \left[Var\left(\overline{E_h}\right)Var\left(\overline{CPUE_k}\right)\right] \quad (23)$$

Total season-long harvest of species *k* within each stratum is estimated as the product of the mean daily harvest for species *k* and the total number of fishable days (tides) within the stratum:

$$\hat{C}_{h,k} = \overline{C_{h,k}}\, D_h \quad (24)$$

The variance of total season-long harvest of species *k* within tide-day stratum *h* is given by:

$$Var\left(\hat{C}_{h,k}\right) = Var\left(\overline{C_{h,k}}\right) D_h^2 \quad (25)$$

Estimation of Total Harvest on a Beach

Total season-long harvest on a beach is estimated for each species as the sum of the within-stratum harvest estimates:

$$\hat{C}_k = \sum_{h=1}^{5} \hat{C}_{h,k} \tag{26}$$

Note that the catch summation in Equation 26 includes not only the estimated catch within the three tide-day strata (ELOW, HIGH, LOW), but also the estimated catch for plus tides and winter (if applicable).

Variance of the total season-long harvest is estimated for each species *k* as the sum of variance estimates for each of the tide-day strata:

$$Var\left(\hat{C}_k\right) = \sum_{h=1}^{3} Var\left(\hat{C}_{h,k}\right) \tag{27}$$

This estimate includes only variance for the three tide-day strata, since variance estimates are not available for plus tides and winter, as noted earlier.

The standard error (SE) of estimated total harvest of species *k* on a beach is given by:

$$SE\left(\hat{C}_k\right) = \sqrt{Var\left(\hat{C}_k\right)} \tag{28}$$

The approximate 95% confidence interval for the total harvest estimate of species *k* on a beach is computed by multiplying the SE by the tabled *t*-value based on *df* degrees of freedom as derived previously in Equation 20 (the *t*-value can only be approximated due to the difficulties in calculating degrees of freedom).

Part II: Analysis of the Flight Route

The analysis of the aerial survey routes in Bivalve Regions 1, 5, 6, 7 and 8 was prompted in part by two developments following the events of September 11th, 2001:

1) The implementation of Temporary Flight Restrictions (TFRs) by the Federal Aviation Administration. The TFRs were established to restrict flights in the vicinity of military establishments. Restricted airspace included the area within a five nautical mile radius of the Bangor Submarine Base dock, a two nautical mile radius originating from the Indian Island Naval Reservation west of Port Townsend, and a three nautical mile radius centered at the Bremerton Naval Shipyards.

2) Severe budget constraints which eliminated one permanent employee in the intertidal project and significantly reduced the project's "goods and services" allotment used to pay for flights.

The combination of new flight restrictions and severe budget constraints forced us to take a fresh look at the entire route structure to see if more efficient routes could be established. In this analysis we asked the following questions:

1) Based on historical patterns of recreational use, which beaches needed to be surveyed and included on the aerial survey routes?
2) Were there any beaches that could be surveyed more efficiently using ground based counts?
3) Could the flight routes be redesigned for greater efficiency?

Methods

Available Data

To analyze historical patterns of recreational use, estimates of effort reported in the final "Recreational Clam and Oyster Harvest Summary" reports for each year between 1990 and 2001 were compiled and entered into a Geographical Information System (GIS) database. This allowed individual beaches to be queried so that a complete use history could be rapidly scanned. All beaches where effort had previously been reported were included in the database. We also computed the mean effort per year over the 11-year record for each beach.

Analysis

Analysis consisted of sequentially examining the recreational use histories on each beach in the GIS database and eliminating beaches where little or no use occurred over the past decade. Beaches where recreational effort averaged less than 100 harvesters per year were candidates for elimination unless they were located along stretches of coastline where other higher use beaches were also found. For example, the annual estimated harvest effort at North Frenchman's Point in Quilcene Bay was only 58 harvesters between 1990 and 2001, but because it was located between the more popular Quilcene Tidelands and Pt.Whitney Tidelands it made sense to include it on any future route. Conversely, the South Eagle Island beach on Anderson Island in southern Puget Sound, was eliminated despite having an average effort of 106 harvesters per year. This was because only minimal effort was found to occur on other public beaches in the area, and one suspect outlier value in 1993 may have artificially inflated the average.

In several cases "orphan" beaches were identified where effort numbers were high enough to justify surveys but the location was considerably distant from other high use beaches. In these cases we considered other alternatives such as arranging for ground based low-tide counts by State Park rangers.

We also identified several areas where surveys had been regularly flown in the past, but where all the public beaches were permanently closed due to pollution. Examples included Sinclair Inlet near Bremerton, and all of the beaches between the Nisqually Delta and Tacoma Narrows. Beaches in these areas were eliminated because it was difficult to justify allocating increasingly scarce resources to survey polluted and closed beaches.

Results

After eliminating beaches with historically marginal effort and beaches in polluted areas, we were able to construct one flight route to take the place of the two routes previously used. Figure 2 shows the beaches that remained on the flight route. The current route starts at Sequim Bay in the Strait of Juan de Fuca and ends at Frye Cove in southern Puget Sound.

The route was designed to ensure that all flight counts would occur close to the absolute minimum daily low tide. Flight counts must be made within a 2-hr window centered on low tide. The current route starts at Sequim Bay and follows the falling tide as it progresses towards southern Puget Sound. Barring adverse wind conditions, the survey starts at Sequim Bay exactly at local low tide and ends at Frye Cove two hours later, again close to the local low tide.

Staff at the Dungeness National Wildlife Refuge volunteered to conduct low-tide effort counts at beaches within the refuge boundaries. This eliminated low-level flights over sensitive bird habitat and considerably shortened the northern end of the flight route.

Summary of the Flight Route Analysis

With the former two-route system employed before 2003, considerable time and expense was devoted to obtaining effort data on beaches of little concern from a management perspective, while providing coverage for only a portion of the more important actively managed beaches on any given flight. The flight route analysis allowed us to combine these routes into one single route that greatly increased the efficiency of our survey efforts. It also allowed us to reallocate survey efforts and obtain additional low-tide counts on beaches where more data were needed. This enhanced the precision of our estimates on the more important beaches.

Part III: Analysis of Effort Stratification

From 1996 through 2002, aerial counts of recreational clam and oyster harvesters were stratified using both ***tide-day strata*** (e.g., weekend minus tides, weekday high tides, etc.) and ***month-group strata*** ("high use" and "low use" months). Table 3 shows the former effort strata described in the 1997 appendix to the Bivalve Management Agreement. There were six tide-day strata (WDP, WEP, WDL, WEL, WDEL, and WEEL) and two month-group strata, defined as ***"high use" months*** (May, June and July) and ***"low use" months*** (March, April, August, and September). Effort counts were therefore separated into 12 strata (6 tide-day strata x 2 month-group strata).

Table 3. Former effort strata defined in the 1997 appendix to the Bivalve Management Agreement and used until 2003. Extreme low tides = - 2.0 ft and below. Low tides = - 0.1 to - 1.9 ft. High tides = 0.0 to 1.9 ft. High Use Month-Group = May, June, July. Low Use Month-Group = March, April, August, September. Weekend includes holidays.

Stratum Name	Week group	Tide height group	Month group
WDP	Weekday	High	High
WDP	Weekday	High	Low
WEP	Weekend	High	High
WEP	Weekend	High	Low
WDL	Weekday	Low	High
WDL	Weekday	Low	Low
WEL	Weekend	Low	High
WEL	Weekend	Low	Low
WDEL	Weekday	Extreme low	High
WDEL	Weekday	Extreme low	Low
WEEL	Weekend	Extreme low	High
WEEL	Weekend	Extreme low	Low

In the sections below, we first evaluated the former tide-day strata and then the month-group strata. The objective in both analyses was to determine if the stratification was advantageous in estimating recreational effort. Thus, we posed the question: Does stratification reduce the variance of effort estimates?

Tide-Day Stratification

Introduction

The sampling design described in the 1997 appendix to the Bivalve Management Agreement was based on a previous analysis of effort data that indicated higher recreational use during periods of very low tides and on weekends. As a result, aerial and ground-based effort surveys were formerly stratified by the categories listed in Table 3. Unfortunately, no documentation has been located to justify on quantitative grounds the selection of the particular set of tide-day strata identified in the analysis. The need to re-analyze historical effort data and test the effectiveness of the previously established strata was recognized in a WDFW Biometric Review (Tagart et al. 1996), and prompted the investigation described below. In this analysis we asked two questions:

1) Is stratification of effort estimates tide-day groupings advantageous? Or, put another way, does stratification by tide-day groupings increase the statistical precision of effort estimates?
2) If so, which are the optimal tide-day strata to use?

Methods

Available Data

Two sets of data were examined in this analysis. To determine if stratification was advantageous we examined data from 1998 to 2001 on 30 Puget Sound beaches. These beaches were selected based on total harvester effort and their relative importance from a management standpoint. Although most beaches included in the analyses were in Bivalve Regions 1, 5, 6, 7 and 8, we also included some beaches in Bivalve Regions 2, 3 and 4 in order to increase sample sizes. With two exceptions, all actively managed beaches where effort in 2001 exceeded 1,000 harvester-days were included in the analysis dataset. Penrose Point State Park was excluded because the season was too short to allow a meaningful analysis. Oakland Bay was excluded due to recent beach boundary changes.

Determining an optimal stratification scheme required additional years of data to obtain meaningful results. We therefore expanded the dataset above to include all effort data between 1994 and 2001. One beach, Rendsland Creek, was dropped from the expanded dataset because of insufficient data in one of the strata categories required during later analysis. This left 29 beaches in the full-period dataset.

Data were generated by running an amended portion of the SAS harvest estimation program, with historical effort files for each year as input. The focus of all analysis was the instantaneous count of harvesters on the beach observed during an aerial survey (the variable E_t in Equation 8). In the SAS harvest program, this same variable is termed *uclam*. Only periods during the year when the beach was open for clam or oyster harvesting were retained in the data set. For example, an oyster beach like Seal Rock FSC was only considered when the oyster season was open. Clam beaches (those *not* formerly designated as actively managed oyster beaches) were included in the dataset only for periods when they were open for clam harvest.

Objectives and Test Procedures

1) Analysis of Variance

Analysis of variance (ANOVA) was used to determine if the variance of the aerial effort counts (E_t) differed significantly between the six strata groupings. Stratification is useful only if the variance *among groups* is greater than the variance *within groups*. If not, then stratification decreases the precision of effort estimates. This is because sample sizes within each stratum decrease when sampling activity is apportioned among more groups. Consistent and significant differences in among-group variance on a majority of beaches would provide strong evidence that stratification was justified.

Initial examination indicated that the E_t data failed to meet the assumptions of normality and constant variance required for ANOVAs. Though ANOVA tests tend to be robust to moderate deviations from these assumptions, we decided to transform the data prior to analysis. Transformation using the Freeman-Tukey (Freeman and Tukey 1950) square root transform $\left(y' = \sqrt{y} + \sqrt{y+1}\right)$ reduced, but did not entirely eliminate these concerns. The Freeman-Tukey transformation is commonly used in cases where count data conform to a Poisson distribution, or when some response variable values are zero or very small (Weisberg 1985).

Following transformation, separate single factor ANOVAs were conducted on each of the 30 beaches in the 1998-2001 dataset. In addition, diagnostic tests were conducted to determine if the assumptions of normality and constant variance were violated. The Shapiro-Wilk test was used to determine if the residuals were normally distributed. The Levene's and Brown-Forsythe tests were used to determine if the variance among groups differed significantly (SAS Institute 1999). After the initial ANOVA tests, a second set of Welch's ANOVA tests were conducted to confirm the earlier results. Welch's ANOVA is robust to the assumption of constant variance (SAS Institute 1999). For all ANOVAs we tested the following hypothesis:

H_0: Variance of effort counts (transformed E_t variable) within groups (tide-day strata) is equal to or greater than the variance among groups.

H_A: Variance of effort counts (transformed E_t variable) among groups (tide-day strata) is greater than the variance within groups.

We tested the null hypothesis with a variance-ratio test (*F*-test) and noted significant results at both the $\alpha = 0.01$ and $\alpha = 0.05$ levels. All ANOVA tests were conducted using the SAS General Linear Models (GLM) procedure. The Shapiro-Wilk test was conducted using the SAS Univariate procedure (SAS Institute 1999).

2) Cluster Analysis

Cluster analysis was used to objectively identify combinations of tide height and weekday that would provide strata groupings with similar variance. For this analysis the E_t data for 1994-2001 was broken into a new set of groupings based on 1-ft increments of tide height and weekend/weekday designations. The groupings are shown below in Table 4.

Table 4. Tide-day groupings of effort data used in the cluster analysis to identify new effort strata candidates. "Weekend" includes holidays.

Stratum Name	Week group	Tide Height (ft)
WEMM	Weekend	< -2
WDMM	Weekday	< -2
WEM	Weekend	< -1 and > -2
WDM	Weekday	< -1 and > -2
WEZ	Weekend	< 0 and >= -1
WDZ	Weekday	< 0 and >= -1
WEP	Weekend	< 1 and >= 0
WDP	Weekday	< 1 and >= 0
WEPP	Weekend	< 2 and >= 1
WDPP	Weekday	< 2 and >= 1

These ten groups were the smallest units practical given available data. Even with eight years of observations in the dataset, Rendsland Creek had to be eliminated from consideration due to an insufficient number of observations in one or more categories.

We used hierarchical clustering methods to recombine the data into a smaller number of groups with similar variance. Cluster analysis is not a statistical test, but rather an exploratory multivariate technique used to detect "natural" groupings in data. It is particularly useful in cases where the data are suspected to be heterogeneous (such as the E_t effort data). Clustering proceeds by linking variables according to a distance measure. The most similar variables are linked first followed by variables of increasing dissimilarity. We tested several linkage methods, but determined that Ward's method was the most appropriate. Ward's method is unique in that it uses an analysis of variance approach to sequentially combine groups that are most similar in terms of variance (Ward 1963). Squared Euclidian distance is the appropriate distance measure to use in combination with Ward's method (Lance and Williams 1967).

Data matrices were constructed using the 1-ft tide-day strata above as variables. We compared results using both total effort and mean effort over the 1994-2001 period as data values. The SPSS statistical package was used for all cluster analysis.

3) Monte Carlo Simulations

We used Monte Carlo simulations to evaluate the statistical precision of different stratification schemes suggested by the cluster analysis. The stratification schemes tested included 2-, 3-, and 4-strata designs suggested by the cluster analysis (see Table 6 in *Results* below), as well as the former six-strata design. For each of these four designs, we simulated sample sizes of n = 15, 20, 30, and 45 "flights" per season on a beach-by-beach basis. For each simulation on each beach, 1,000 bootstrap replicates of size n were drawn from the pool of all 1994-2001 effort counts for the particular beach (E_t in Equation 8, called *uclam* in the SAS harvest estimation program). All bootstrap re-sampling was performed with a user-written SAS program. In drawing the bootstrap samples, total sample size n was allocated within each tide-day stratum (n_h) according to an optimal allocation formula for stratified random sampling (Thompson 1992):

$$n_h = \frac{nN_h\sigma_h}{\sum_{h=1}^{L} N_h\sigma_h} \tag{29}$$

where

n_h = the number of samples within tide-day stratum h
N_h = the total number of units in tide-day stratum h (i.e., the total number of available daylight clamming tides within stratum h) averaged for each stratum over the years 1994 – 2001. See Table 5 for average N_h values.
σ_h = the population standard deviation for tide-day stratum h averaged for each stratum over the years 1994 – 2001.
L = the total number of strata (i.e., either 2, 3, 4, or 6 strata).

The sample allocation following the formula above estimates a population mean or total with the lowest variance for a fixed total sample size n with stratified random sampling (Thompson 1992). Optimal allocation of samples within strata was calculated for each beach separately using Equation 29 above, and the resulting beach-specific allocations are shown in Appendix Tables 1, 2 and 3. The optimal sample size within each stratum was then averaged to obtain a single "best-fit" optimal allocation for all beaches (Table 5).

Once the bootstrap samples were allocated and drawn for a given beach and stratification design, a value of mean E_t was calculated within each stratum h for each of the 1,000 bootstrap replicates. Then, a grand mean effort ($\overline{E_{t,h}}$) was calculated for each stratum h, averaging *all* the 1,000 bootstrap samples.

Table 5. Optimal sample size allocation within tide-day strata for four tested stratification designs, averaged over beaches in Bivalve Regions 1, 5, 6, 7 and 8. The 2-, 3-, and 4-strata designs are defined in Table 6. Four possible sample sizes (*n*) used in the Monte Carlo simulations are shown. $\overline{N_h}$ = average total number of daylight clamming tides available during March – September, averaged over 1994-2001. Equation 29 was used to calculate the stratum allocations. All sample sizes are rounded, and some within-stratum sample sizes were adjusted to ensure a minimum of two samples per stratum.

Two strata	***HIGH***	***LOW***
$\overline{N_h}$	111	33
n = 15	7	8
n = 20	10	10
n = 30	15	15
n = 45	22	23

Three strata	***ELOW***	***HIGH***	***LOW***
$\overline{N_h}$	5	111	28
n = 15	3	7	5
n = 20	3	10	7
n = 30	4	16	10
n = 45	6	24	15

Four strata	***ELOW***	***HIGH***	***LOW***	***MED***
$\overline{N_h}$	5	58	28	53
n = 15	2	3	5	5
n = 20	3	4	7	6
n = 30	4	6	11	9
n = 45	6	9	17	13

Six strata	**WDEL**	**WDL**	**WDP**	**WEEL**	**WEL**	**WEP**
$\overline{N_h}$	12	43	46	5	18	20
n = 15	3	2	2	3	3	2
n = 20	3	4	3	3	5	2
n = 30	5	6	3	5	8	3
n = 45	8	9	4	7	12	5

For example, 1,000 samples of n = 45 were drawn from the pooled 1994-2001 values of E_t at Dosewallips State Park with the three-strata design. Each of the 1,000 replicates therefore consisted of six randomly-drawn values of E_t in the ELOW stratum, 24 values randomly-drawn values in the HIGH stratum, and the remaining 15 values from the LOW stratum; optimal sample sizes for the three-strata scheme and n = 45 are given in Table 5. The mean of all six ELOW values was calculated for each of the 1,000 replicates, as were the means for the 24 HIGH values, and the 15 LOW values. This procedure resulted in 1,000 mean values for the ELOW stratum at Dosewallips State Park, 1,000 means for the HIGH stratum, and 1,000 means for the LOW stratum. A grand mean for each of the three strata was then calculated; for example, the grand mean for the ELOW stratum ($\overline{E_{t,ELOW}}$) was the average of all 1,000 mean E_t values in the ELOW stratum at Dosewallips State Park.

Similarly, sample variances were calculated for the mean E_t estimate in each stratum, and a mean sample variance (s_h^2) for all 1,000 samples was calculated for each stratum h.

Using these grand mean effort values for each stratum, a stratified sample mean effort (mean E_t) was calculated for each beach per Thompson (1992):

$$\overline{E_{t,st}} = \frac{1}{N}\sum_{h=1}^{L} N_h \overline{E_{t,h}} \qquad (30)$$

where

$\overline{E_{t,st}}$ = the stratified sample mean observed effort (E_t)

$\overline{E_{t,h}}$ = the grand mean observed effort (E_t) within stratum h (the mean of 1,000 bootstrap mean E_t values in stratum h)

N = the total number of units in all strata (i.e., the total number of available clamming days)

An unbiased estimator of the variance of the stratified sample mean effort for each beach was calculated per Thompson (1992) as:

$$Var\overline{E_{t,st}} = \sum_{h=1}^{L}\left(\frac{N_h}{N}\right)^2\left(\frac{N_h - n_h}{N_h}\right)\frac{s_h^2}{n_h} \qquad (31)$$

where

s_h^2 = the mean sample variance within stratum h (the mean variance of 1,000 bootstrap samples in stratum h)

The standard error (SE) and relative standard error (RSE) were then calculated for each beach, stratification scheme, and sample size n. An approximate 95% confidence interval was calculated in each case following the methods of Thompson (1992), using tabled t-values and Satterthwaite's (1946) approximation for degrees of freedom. Finally, the "proportion error" of the estimate of the stratified mean effort was calculated as

$$\text{Proportion Error} = \frac{95\%CI\,\overline{E_{t,st}}}{\overline{E_{t,st}}} \qquad (32)$$

The proportion error was calculated for each stratification design and sample size n on 28 beaches. A mean proportion error was also calculated for each stratification design and sample size, averaging the values for proportion error over all 28 beaches. This mean proportion error averaged over all beaches was used to compare the statistical precision of the different stratification schemes and sample sizes.

4) Empirical Tests

We used the actual observed effort values (E_t) for each beach and each year 1994 through 2001 in order to estimate stratified sample mean effort ($\overline{E_{t,st}}$) and its variance using the 2-strata, 3-strata, and 4-strata schemes. Equations 30 and 31 above were used to calculate stratified sample mean effort and its variance for each beach-year. These empirical tests differed from the Monte Carlo simulations in three aspects: **(1)** actual E_t values for Beach *x* in Year *y* were used in the calculations, rather than bootstrap samples drawn from the pooled 1994-2001 data on Beach *x*, **(2)** actual total sample sizes (n) for Beach *x* in Year *y* were used in the calculations, rather than a range of simulated total sample sizes; likewise, sample sizes within each stratum (n_h) were not optimally allocated, except by chance, and **(3)** sample variances could not always be calculated for some beach-years, because it sometimes happened that no samples were taken in one or more of the strata; likewise, it sometimes occurred that strata containing more than one sampling unit ($N_h > 1$) were sampled only once during a year ($n_h = 1$), also resulting in an error value for sample variance.

Stratified sample mean effort ($\overline{E_{t,st}}$) was calculated for each beach and each year from 1994 through 2001. Sample variances, 95% CIs, and the proportion error were also calculated for each beach and year estimate. Two criteria were used to compare the three stratification designs: **(1)** Mean proportion error. First, the proportion error for each beach and year was calculated using Equation 32 above. Next, a mean proportion error averaged over all beach-year estimates was calculated, *excluding those estimates for which variance could not be calculated* (due to insufficient within-stratum samples), and **(2)** the number of estimates where variance could not be calculated due to insufficient sampling within strata.

Results

1) Analysis of Variance

ANOVA results indicated that *among group* variance was greater than *within group* variance on all but two of the 30 beaches tested (Appendix Table 4). Tests were significant at the $\alpha = 0.01$ level on the 28 beaches where the null hypothesis was rejected. This meant that *at least* one of the strata among the six strata tested had significantly different variance. The tests for constant variance (Levene's and Brown-Forsythe) provided additional evidence that variance differed among the six strata groupings. Significant tests are indicated by asterisks; one asterisk for the $\alpha = 0.05$ level and two for $\alpha = 0.01$ level.

Because the constant variance tests and the Shapiro-Wilk tests for normality indicated that key assumptions for ANOVA testing might have been violated, a second set of more robust Welch's ANOVA tests were also conducted. The Welch's ANOVA tests confirmed earlier results (Appendix Table 5). Once again, there were only two of 30 beaches where the null hypothesis could not be rejected. If significance levels had been set at the $\alpha = 0.10$ level, the Welch's ANOVA would have given significant results for all 30 beaches.

2) Cluster Analysis

Cluster analysis produced four new candidate strata groupings based on the tide-day combinations described above. Figure 4 (panel A) shows the final cluster results using Ward's method and total effort data from 1994 through 2001. Figure 4 (panel B) shows the resulting clusters using Ward's method with mean effort data from 1994 through 2001. Camano Island State Park was eliminated from the mean effort cluster matrix due to an outlier value in the WEP category.

Starting with all of the tide-day combinations in one big group, the dendrograms in Figure 4 show the sequential splitting of the initial group into increasingly smaller groups based on their similarity in terms of variance. The clustering proceeds until each tide-day combination is fully separated from all others. Clusters that resist being separated (indicated by long branches) are the most similar. Branches with separation points located furthest to the left (near zero on the distance scale) indicate groupings that are most dissimilar. The longer a group remains joined, the stronger is the similarity.

Both dendrograms showed an early split into two distinct groups that could be loosely defined as low use (mostly weekday and high tides) and high use (mostly weekend and low tides). An extreme high use group (WEMM) was separated out next, and can be defined as all effort on extreme low weekend tides (≤ 2.0 ft). The remaining divisions occurred fairly close to zero on the distance scale and indicated groupings with only small relative differences in variance.

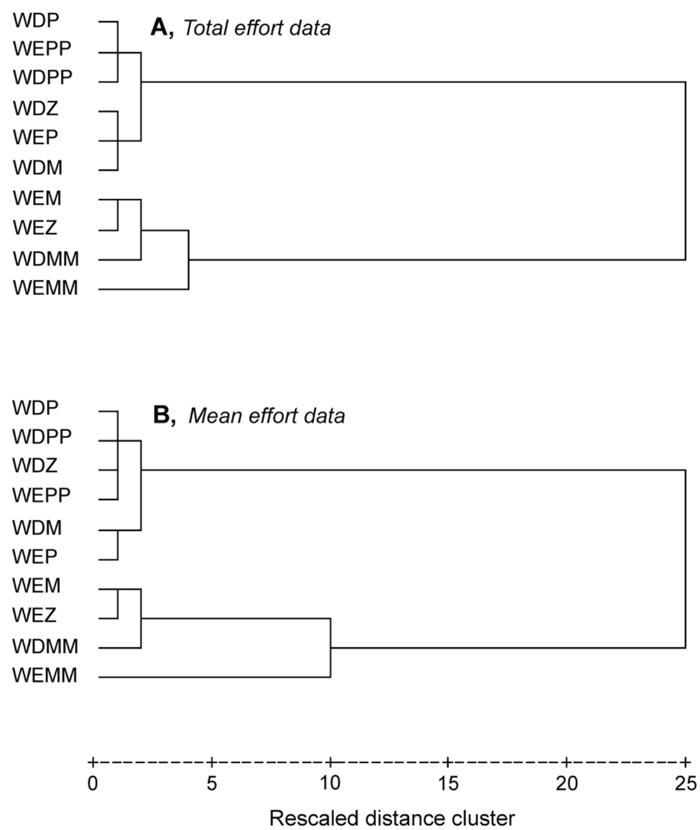

Figure 4. Cluster analysis solutions for tide-day effort stratification using total effort data (panel A) and mean effort data (panel B) for years 1994-2001. Candidate strata groupings are based on 1-ft tide-day combinations described in Table 4

Visual inspection of the dendrograms from both the total effort data and the mean effort data indicated that there were three distinct groupings, characterized as low use, high use, and extreme high use. Inspection of the total effort dendrogram also suggested some justification for splitting the low use group into two separate groups, despite the fact that variance differences were likely to be small. We consequently defined four new candidate strata groupings that we labeled HIGH, MED, LOW, and ELOW. These groupings formed the basis of the new 4-strata design. We also formed a 3-strata design by merging the HIGH and MED categories while keeping the LOW and ELOW categories separate, and a 2-strata design by merging the HIGH and MED groups and the LOW and ELOW groups. Table 6 shows the candidate tide-day stratification designs that served as a basis for Monte Carlo simulations and empirical tests.

Table 6. Three candidate tide-day stratification designs for effort estimation, as suggested by the cluster analysis of 1994-2001 effort data. Extreme low tides = -2.0 ft and below; low tides = -0.1 to –1.9 ft; high tides = 0.0 to 1.9 ft. "Weekend" includes holidays.

Design	Name	Description
2 Strata	HIGH	Weekend and weekday high tides, weekday low tides
	LOW	Weekend and weekday extreme low tides, weekend low tides
3 Strata	ELOW	Weekend extreme low tides
	HIGH	Weekday low tides, weekend and weekday high tides
	LOW	Weekday extreme low tides, weekend low tides
4 Strata	ELOW	Weekend extreme low tides
	HIGH	Weekday high tides, weekend tides < 2 ft and ≥ 1 ft
	LOW	Weekend low tides, weekday extreme low tides
	MED	Weekday low tides, weekend tides < 1 ft and ≥ 0 ft

3) Monte Carlo Simulations

The results of all Monte Carlo simulations on 28 beaches are shown in Appendix Table 6. For each beach, stratification design and sample size, Appendix Table 6 shows the mean proportion error (i.e., the 95% CI on stratified sample mean effort $\overline{E_{t,st}}$ divided by stratified sample mean effort itself). The proportion error given in Appendix Table 6 is the mean of all 1,000 Monte Carlo simulations, each of which provided an estimate of proportion error. The grand mean of all 28 beaches is shown on the bottom row of Appendix Table 6.

Figure 5 shows the grand mean proportion errors for all 28 beaches (the bottom row of values in Appendix Table 6). All four stratifications performed almost identically in terms of statistical precision at sample sizes $n > 20$ "flights." At sample sizes of $n > 20$, the four-strata design produced, on average, an estimate of stratified mean effort with the lowest proportion error, and the two-strata design involved the highest proportion error. However, Figure 5 shows that the difference in proportion error between the four stratification designs was negligible. At sample sizes $n < 20$, however, proportion error began to differ markedly, with the three-strata design having the lowest average proportion error. For all four stratifications, sample sizes of $n > 30$ produced estimates that, on average, had proportion error of around 0.40 (i.e., RSE ~ 0.20).

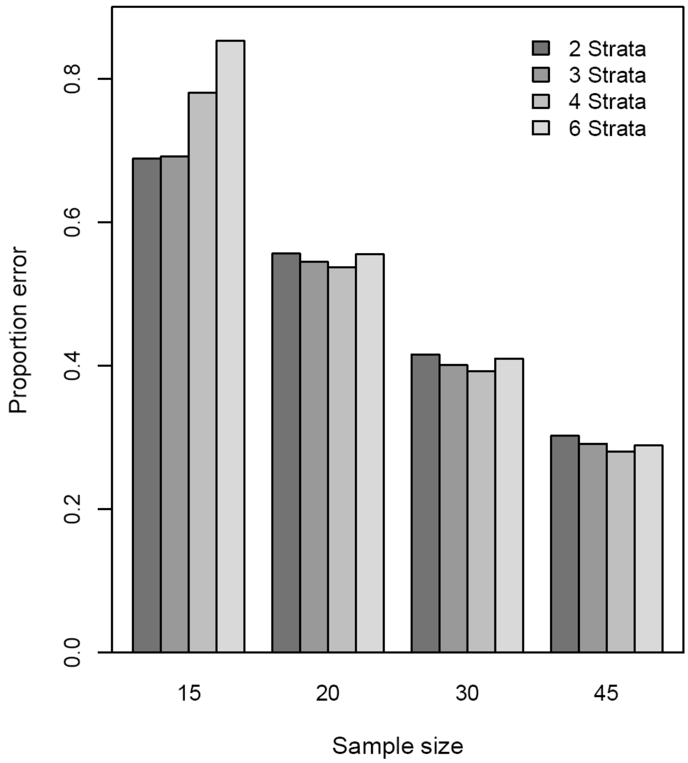

Figure 5. Grand mean proportion error for four different effort stratification designs and four sample sizes ranging from 15 to 45 flights per season. Proportion error is the 95% CI on stratified mean effort, expressed as a proportion of the mean effort estimate itself. Grand mean proportion errors are taken from Appendix Table 6, bottom row, and represent the mean of Monte Carlo simulations on 28 public beaches.

4) Empirical Tests

Empirical tests using actual effort counts on 28 beaches in the years 1994-2001 produced results very similar to the Monte Carlo simulations, in which effort counts were re-sampled from the pooled 1994-2001 data and optimally allocated within strata. Table 7 shows the results of the empirical tests on all 28 beaches. A total of 222 beach-year effort estimates were available from the historical data, including estimates for which variance could not be calculated (i.e., those returning an “error” for the estimate of variance). Average sample size (number of flights per beach per season) was n = 30.42. Not surprisingly, the number of estimates for which variance could not be calculated increased as the number of strata increased. For example, of 222 total estimates, only nine failed to produce a variance estimate when two strata were used, whereas errors resulted in 29 of the estimates using three strata, and 32 using four strata. Of the 222 effort estimates, there were 190 with valid estimates of variance using all three stratification schemes; these 190 estimates were used to compare the overall statistical precision of the three stratifications. Based on these 190 estimates, the proportion error averaged over all 28 beaches was virtually identical for the 2-strata, 3-strata, and 4-strata schemes, and ranged only from

0.3704 to 0.3870. Failure to estimate variance was due in more than half the cases to a sample size of zero within one or more strata.

Table 7. Results of empirical tests estimating stratified sample mean effort ($\overline{E_{t,st}}$) on 28 beaches from 1994-2001 using three different tide-day stratification designs. "ERR variance" refers to estimates of effort for which a variance estimate could not be calculated due to insufficient samples within a stratum. The number of total beach-year estimates, including those with ERR variance = 222 in each of the three designs; 190 of these estimates had non-ERR variance in all three designs. The mean number of daily effort counts in all strata = 30.42.

Criterion	***2 Strata***	***3 Strata***	***4 Strata***
Mean Proportion Error of all estimates with non-ERR variance	0.3736	0.3704	0.3870
Number of ERR variance estimates	9	29	32
Number of ERR variance estimates due to zero samples in a stratum	5	20	18

5) Summary of Tide-Day Stratification Results

The first question we asked was: Is stratification of recreational clam and oyster effort sampling by tide-day groupings advantageous? The ANOVA performed on 1998-2001 effort data indicated that *among group* variance using the former six tide-day strata was significantly greater than *within group* variance on all but two of the 30 beaches tested. This meant that *at least one* of the former six tide-day strata had significantly different variance, and that some stratification was therefore likely to be advantageous.

The next question we asked was: Since ANOVA suggests that *some* stratification is advantageous, what are the optimal strata? Cluster analysis using all 1994-2001 effort data arranged in 1-ft increments of tide height suggested that there were four strata groupings that might provide reasonably precise effort estimates. Cluster analysis also suggested that these four strata might be re-arranged to form three strata, or possibly even two strata. Thus, cluster analysis provided us with three candidate stratification designs for further testing.

We next performed a series of tests with all the 1994-2001 effort data in order to compare the statistical precision of the three new candidate stratification designs, as well as the former six-strata design. We ran Monte Carlo simulations with all the data from each of 28 beaches. For each beach, we produced 1,000 simulated data sets from the effort counts, and calculated effort and variance estimates for each one. Within each of the four stratification designs, we simulated sample sizes of between 15 and 45 flights per season, and allocated samples within the strata so as to provide the highest statistical precision. When the results of these simulations were averaged over all 28 test beaches, we found that all four stratification designs produced effort estimates with roughly equal precision when more than 20 flights were flown per beach each season.

We also conducted empirical tests (as contrasted with simulations) using the actual effort counts on 28 beaches during the period 1994-2001. These tests allowed us to compare the precision of effort estimates had they been calculated using the 2-strata, 3-strata, and 4-strata designs. As with the Monte Carlo simulations, the results of empirical tests suggested that when 30 flights were flown over a beach in a season, the precision of the effort estimates was roughly the same regardless of which stratification design was used.

Based on the Monte Carlo simulations and empirical tests described above, we chose the 3-strata design for sampling recreational effort. Admittedly, the advantages of this design compared to the 2-strata and 4-strata were slight. Although the 2-strata design was simpler and involved roughly the same level of statistical precision, the 3-strata design preserved the ELOW stratum, which is convenient for reporting and sample scheduling purposes. Likewise, the 4-strata design was slightly more complex than the 3-strata design, and was somewhat more prone to under-sampling the smaller strata.

Preservation of the ELOW stratum was also beneficial because on many beaches a majority of the harvest occurs during the handful of days during the year when ELOW tides occur. It is therefore often both practical and desirable to obtain effort counts on *all* ELOW tides in a given year. Prior to 1990 aerial surveys were *only* flown on days with ELOW tides. Continuing to sample a high percentage of ELOW tides provides the continuity in sampling required to compare rates of harvest effort over time within this important strata.

Month-Group Stratification

Introduction

The 1997 appendix to the Bivalve Management Agreement defined two month-group strata that augmented the six tide-day strata: ***high use months*** (May, June, and July) and ***low use months*** (March, April, August and September). There did not appear to be any documented, quantitative justification for the “high use” and “low use” month-group stratification. Moreover, cursory examination of the available data provided no obvious rationale for the high use and low use month grouping. Figure 6 shows frequency distributions of all 1994-2001 effort counts on all Puget Sound public beaches, grouped by two of the three tide-day strata (HIGH and LOW) and both of the month-group strata (high use and low use). No graphs for the ELOW tide-day stratum (weekend extreme low tides) are shown, because weekend extreme low tides occur almost entirely within high use months. Figure 6 shows little obvious difference in the frequency distribution of harvesters counted during low use and high use months. Figure 6 provided only an exploratory look at the data; it was not beach-specific, nor was it a hypothesis test. Nevertheless, it cast suspicion on the usefulness of “month-groups” as a stratification variable, and prompted further analysis described below.

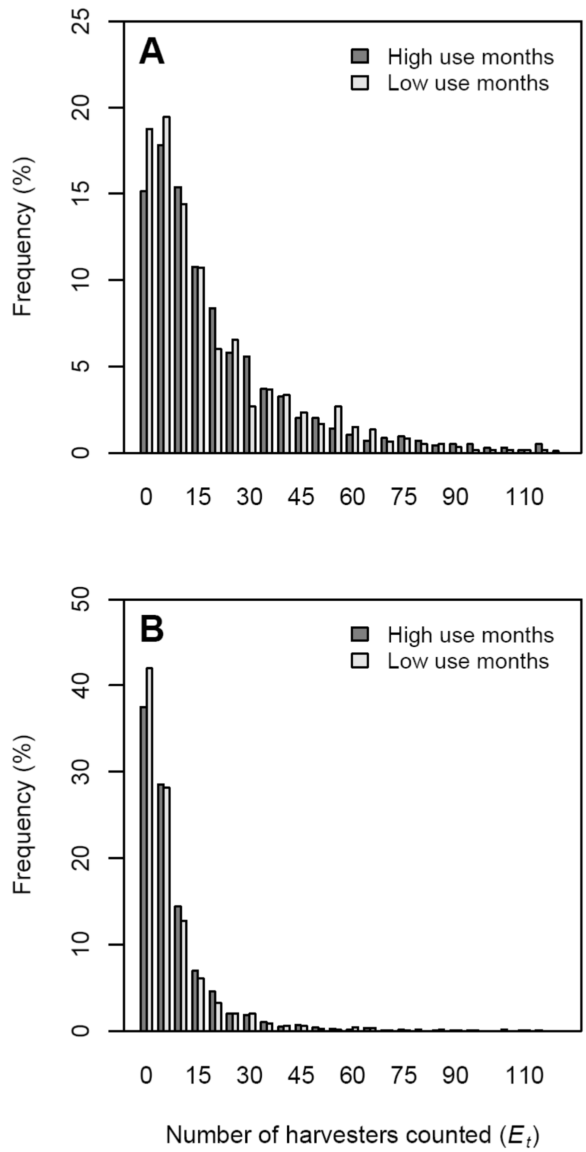

Figure 6. Frequency distribution of instantaneous effort counts (E_t) on all Puget Sound public beaches, 1994-2001. Frequency distributions are grouped by the LOW tide-day stratum (panel A) and the HIGH tide-day stratum (panel B). For clarity, the x-axis was trimmed at E_t = 120 harvesters.

In this analysis, we asked the question “Given that it is advantageous to stratify effort estimates by the three tide-day strata ELOW, HIGH, and LOW, is it *also* advantageous to further stratify effort by the high use and low use month-groups?

Methods

Available Data

Effort counts were analyzed using data from 1994 to 2001 on 27 Puget Sound public beaches. These beaches were selected because they represented the most important actively managed beaches in Puget Sound, and because the harvest season included both high use and low use months. Many beaches, for example, were excluded because they were typically open only during high use or low use months, and therefore provided no data for month-group comparison. A subset of 13 of these 27 beaches was used in the empirical analysis; this subset represented beaches that were typically open for long periods in both high use and low use months. To save time, only data from 1998 to 2001 were used in the empirical analyses.

All data were exported from the historical SAS harvest program files. The SAS program variable *mogrp* identified a particular sample as being in the high use or low use month-group (*mogrp* = H or L). When conducting ANOVA, the effort response variable tested was the instantaneous count of harvesters observed during an aerial survey at time t on day d (E_t in Equation 8, called *uclam* in the SAS harvest program). The effort response variable for the empirical analyses was the estimated total number of harvesters using the beach all day on day d ($\hat{E}_d$ in Equation 8, called *clmuse* in the SAS harvest program). As noted above, the expanded variable $\hat{E}_d$ is an almost linear function of E_t, so analyses of variance conducted on either of the two variables will tend to have very similar results. The variable $\hat{E}_d$ was considered more appropriate for the empirical analyses only because it provided an actual estimate of stratified mean daily effort as calculated by the SAS harvest program.

When a beach was open during a particular year at different times for clams and oysters, we limited analyses to “same-season” data. For example, on Wolfe Property State Park in 1996, we eliminated from analyses two samples in the LOW tide-day stratum when the beach was closed for clams but open for oysters; this left 12 samples during which time the season was open for both clams and oysters.

Objectives and Test Procedures

1) Analysis of Variance

The objective was to test whether inclusion of the month-group strata decreased the variance of mean daily effort (i.e., mean E_t). Stratification is useful only if the variance *among groups* (in this case the two month-group strata) is greater than variance *within groups*. If not, stratification is not useful, and actually decreases the precision of the estimated mean effort.

To be meaningful, this test of high use and low use month-groups had to be carried out within the three previously established tide-day strata (ELOW, HIGH, and LOW; see Table 6). For example, we expected, based on the analysis presented earlier in *Tide-Day Stratification*, that the effort counts in samples from the LOW tide-day strata would be significantly higher, on average, than samples in the HIGH tide-day strata. Thus, valid tests of the month-group stratification had to be carried out separately for samples within the ELOW, HIGH, and LOW tide-day strata. On Beach *a* in Year *x*, for example, we conducted three ANOVAs. In practice, however, separate tests only needed to be carried out with the samples from HIGH and LOW tide-day strata, because ELOW samples (weekend extreme low tides) occurred almost exclusively in the high use months of May, June, and July. Exploratory two-way ANOVAs concurrently testing *both* the month-group and tide-day strata were initially carried out, but analysis of residuals suggested that they violated one of the principal assumptions of ANOVA: homogeneity of variances. In almost all cases, the samples from HIGH and LOW tide-day strata were highly heteroscedastic (i.e., variances were unequal). This was to be expected, since we specifically defined the HIGH and LOW tide-day strata based on their extremely high among-group variance.

For each sampled beach and year, we therefore used a single factor ANOVA to test the null hypothesis of no month-group effect within the HIGH and LOW tide-day strata. Each beach-year sample thus involved two separate ANOVAs. We also performed two ANOVAs (again, within the HIGH and LOW tide-day strata) on *all* 1994-2001 data from *all* beaches. For all ANOVAs, we tested the following hypothesis:

H_0: Variance of instantaneous effort counts (variable E_t from Equation 8) within groups (month-group strata) is equal to or greater than the variance among groups.

H_A: Variance of instantaneous effort counts (variable E_t from Equation 8) among groups (month-group strata) is greater than variance within groups.

We tested the null hypothesis with a variance-ratio test (F-test) and noted significant results at both the $\alpha = 0.05$ and $\alpha = 0.10$ levels. All ANOVA tests were carried out using the statistical package R (Version 1.5.1), an open-source application based on the S language.

2) Empirical Analyses

To perform an empirical test of the month-group strata on selected beaches, we simply estimated recreational effort *twice*, the first time *including* the month-group strata, and the second time *ignoring* the month-group strata. Each of the two runs produced an estimate of the stratified daily mean effort and its variance. We then compared the relative standard error (RSE) of both estimates. Empirical testing that compared both methods thus provided a way to ground truth the inferences about statistical precision of effort estimates that we made from the ANOVA.

Although we would expect ANOVA and empirical analyses to be reasonably consistent, there are several differences which are worth noting: **(1)** the ANOVA procedure tested the variable E_t, the observed instantaneous effort counts from flights; actual effort estimates used for management rely on the variable $\hat{E}_d$ (all-day effort on day d, expanded from E_t using an egress ratio expansion factor; see Equation 8). Although we have noted that $\hat{E}_d$ is a nearly linear function of E_t, empirical tests provided some assurance that there was no unforeseen magnification of the difference between these two variables when estimating season-long effort on a beach, **(2)** season-long effort estimates involve multiplying mean stratified daily effort (stratified mean E_t) within each stratum by the number of available harvesting days within that stratum; again, we could not be sure of the effect without empirical testing, and **(3)** the ANOVA procedure described above tested month-group strata within the HIGH and LOW tide-day strata. Actual estimates of season-long effort also include effort estimates from the ELOW stratum (weekend extreme low tides), which occur almost exclusively in "high-use" months. Empirical analyses provided us with a sense of how the precision of the overall effort estimate was affected by the ELOW stratum.

We used data from 13 beaches to estimate a stratified sample mean daily effort (stratified mean daily $\hat{E}_d$) and its variance. These particular beaches were selected because they were typically open long enough during the year to include many samples from both month-groups. We made estimates for each beach for each of four years (1998-2001).

Two estimates were made for each beach-year, one utilizing six strata (3 tide-day strata x 2 month-group strata), and the other ignoring month-groups and relying only on the previously established three tide-day strata (LOW, HIGH and ELOW). Calculations of the stratified sample mean (mean $\hat{E}_d$) and its variance were carried out using the standard formula for stratified random sampling (e.g., Thompson 1992, pages 104-105). The number of total tides available for harvest in each stratum was taken from historical SAS program files, and modified accordingly for beaches open less than year-round. The relative standard error (RSE) of each estimate was expressed as [standard error of mean $\hat{E}_d$ /mean $\hat{E}_d$]. All calculations were carried out in Excel.

Results

1) Analysis of Variance

Neither of the two ANOVA results using the "lumped" data from all years and all beaches was significant at the $\alpha = 0.05$ level. The ANOVA comparing "high use" and "low use" month-groups within the HIGH tide-day stratum resulted in an F-value of 2.327 ($P > F = 0.1272$, $n = 3{,}870$). The ANOVA comparing "high use" and "low use" month-groups within the LOW tide-day stratum resulted in an F-value of 2.699 ($P > F = 0.1005$, $n = 2{,}592$).

The ANOVA summary results from individual beach-year tests are shown in Appendix Table 7. Of a total of 432 individual tests on 27 beaches from 1994 through 2001, 81 of the tests could not be used in comparing the month-group strata (listed as "NA" in Appendix Table 7) because there were not sufficient samples within one or more of the strata.

Of the 351 valid ANOVAs, only six were significant at the $\alpha = 0.05$ level, and only 26 were significant at the $\alpha = 0.10$ level (indicated by shading in Appendix Table 7). Beaches with significant tests at the $\alpha = 0.05$ level were: WINAS-Maylor Pt East (1999); Fort Flagler State Park (1998); South Indian Island County Park (1999); Seal Rock FSC (1998); Eagle Creek (1997); and Quilcene Tidelands (1995).

Of the 26 tests which were significant at the $\alpha = 0.10$ level, it is interesting to note that in eight instances, the mean effort in "low use" months was higher than in "high use" months.

2) Empirical Analyses

Appendix Table 8 shows the test results on 13 beaches in which stratified mean daily effort was estimated with and without the month-group strata (i.e., with six month-group /tide-day strata, and then with only the three tide-day strata).

Of 50 comparable tests, the RSE of stratified mean daily effort using the month-group strata was lower in only ten cases (indicated by shading in Appendix Table 8).

In 17 of 50 cases, variance on the effort estimate could not be calculated using the month-group strata because there was only a single sample within a stratum, or no sample at all. Errors of this type happened in *all* the 2001 tests stratified by month-group; in that year there were two tides in the weekend extreme low stratum (ELOW) that occurred during “low use” months, and neither tide was sampled. Four variance errors occurred in years other than 2001 when using the month-group strata (= 10.8% of all non-2001 cases); in these cases, only one sample was taken in the ELOW/ “low-use” month stratum. When month-group strata were ignored, only one variance estimate could not be calculated (Dosewallips State Park, 2000); in this case, only one of the two ELOW stratum tides had been sampled.

In three cases where the month-group strata were used, no estimate of stratified mean daily effort could be calculated (Birch Bay, Wolfe Property, and Potlatch State Parks). These errors occurred because the LOW tide-day stratum in “low use” months contained no samples. When month-group strata were ignored, there were no cases where an estimate of stratified mean daily effort could not be calculated.

Of the ten tests in which RSE was lower using the month-group strata, six tests corresponded to ANOVA results which were significant at either the $\alpha = 0.10$ or $\alpha = 0.05$ level (West Penn Cove, 1998; WINAS-Maylor Pt East, 1998 and 1999; Fort Flagler State Park, 1998; Dosewallips State Park, 1999; and Seal Rock FSC, 1998).

The empirical tests also demonstrate that the estimate of stratified mean daily effort itself is not greatly affected by the choice of stratification. Ignoring the month-group strata produced higher effort estimates in 28 out of 47 cases (= 59% of the cases), but the magnitude of the difference was always small. Overall, effort estimates using both methods produced almost identical results (mean daily effort averaged over all comparable trials was 51.57 harvesters using the month-group strata versus 51.86 harvesters ignoring the month-group strata).

3) Summary of Month-Group Stratification Results

Both ANOVA and empirical tests on the 1994-2001 data from 27 beaches indicated that the former “high use” and “low use” month-group stratification was not advantageous in estimating effort.

Disadvantages of the former month-group stratification can be summarized as follows:

1) Using the month strata, the *within-group variance* was usually higher than the *among-group variance*. In such cases, stratification is not useful, and actually decreases the precision of estimated effort. This inference from the ANOVAs was corroborated in the empirical tests, in which the month-group stratification produced a more precise estimate of effort in only ten of 50 cases.

2) Stratifying with month-groups would double the number of effort strata (2 month-group strata x 3 tide-day strata). In theory, it would be possible to adequately sample each of the six strata (i.e., sample each stratum at least twice), but inadequate sampling frequently occurred in practice. This was demonstrated in the empirical tests, where variance estimates – and sometimes even the estimate of mean daily effort itself – could not be calculated 10% of the time. These errors were almost unavoidable with month-group strata, since flight cancellations due to weather frequently resulted in under-sampling the smaller strata.

3) Even if month-group strata could be adequately sampled, flight scheduling becomes complicated if samples covering six strata must be scheduled versus scheduling only among three strata.

4) When the SAS harvest estimation program used month-group strata (from 1996 through 2002), the software program was overly complicated. This complication resulted not only from the increased number of effort strata, but also because the former program relied on a complex series of "data substitutions" to avoid errors due to the inevitable under-sampling in some strata.

In summary, eliminating the "high use" and "low use" month-group strata produced more precise estimates of harvester effort, while at the same time simplifying flight schedules and the harvest estimation program.

Part IV: Analysis of the Effort Expansion Factor

Counts of sport clam and oyster harvesters obtained during aerial surveys or ground-based low-tide counts provide an instantaneous measure of harvest effort on any given beach. While such counts provide an accurate "snapshot" of effort at the instant the plane flies overhead, they do not represent the total number of harvesters using the beach over the entire day. To generate an estimate of harvester effort over the entire day ("all-day effort"), an expansion factor needs to be applied to the instantaneous count obtained during the flyover.

The effort expansion factor used from 1996 through 2006 was based on a model of harvester behavior derived from "ingress" surveys conducted at ten WDFW Region 6 beaches in 1990 and 1992. These surveys were conducted within a 6-hr time block centered on the time of the local low tide, an interval that was expected to include virtually all harvesters. The total number of shellfish harvesters entering ("ingressing") the beach during the 6-hr time block was recorded, along with instantaneous counts of harvesters present on the beach at half-hour intervals ("activity counts"). If harvesters were already present on the beach at the beginning of the survey, they were added to the total "ingress" count. The ingress ratio for any given half-hour increment was calculated as:

$$R_t = \frac{H_t}{H_s} \tag{33}$$

where

R_t = the egress ratio at time t (the proportion of all-day effort present at time t on the survey day)

t = the time (in minutes) relative to local low tide (e.g., at local low tide, $t = 0$; one half hour later, $t = 30$; one hour prior to local low tide, $t = -60$)

H_s = the total number of harvesters observed leaving ("egressing") the beach during the 6-hr time interval spanning local low tide, including any harvesters still present when the survey ended

H_t = the total number of harvesters observed on the beach at time t (the "activity count" at time t)

Data from a total of 80 surveys were pooled to generate an ingress curve assumed to represent harvester behavior on the "average beach." Ingress ratios from all 80 surveys were therefore averaged to produce the curve. The mean ingress ratio for any given half-hour increment t was calculated as:

$$\overline{R}_t = \frac{1}{n}\sum_{i=1}^{n} R_t \tag{34}$$

where

$\overline{R}_t$ = the mean egress ratio (i.e., the proportion of all-day effort expected at time t)

n = the number of estimates of R_t available at time t (for most t, this is equal to the total number of egress surveys)

Model points were interpolated for times between the observed half-hour survey increments so that an ingress ratio could be calculated for any minute during a 4.5-hr time block straddling low tide. A separate ingress model was generated for beaches where oysters were the predominant species harvested.

Besides the former model described above and used from 1996 through 2006, a number of different ingress models had been used prior to that time. These models were used to expand harvester counts since the inception of systematic aerial surveys in 1969. These older models were refined over time as more data became available. For comparison, several previous ingress models are plotted in Figure 7, along with the mean of all available ingress data collected between 1989 and 2005 (solid black line).

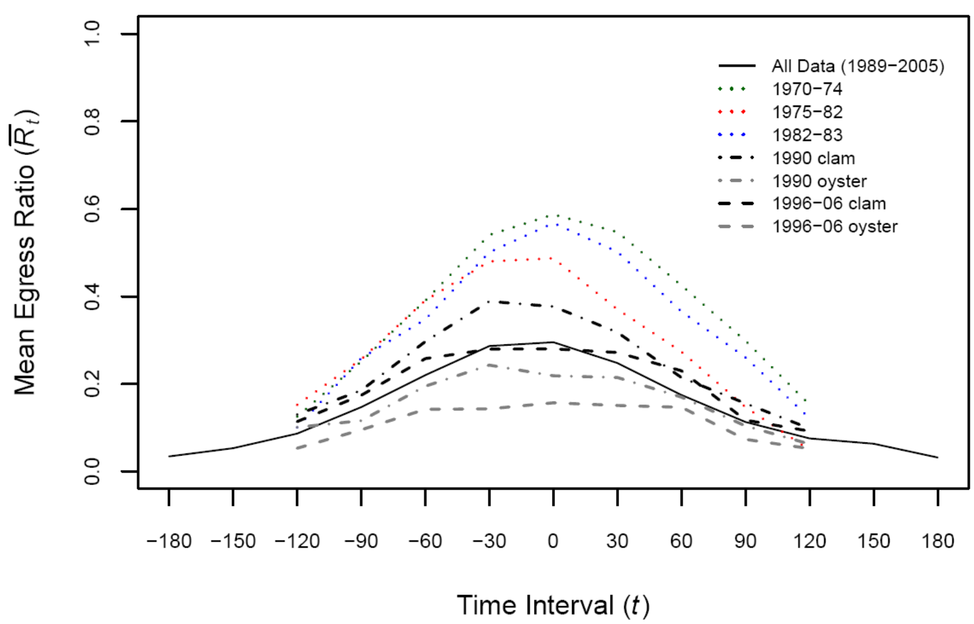

Figure 7. A comparison of past ingress/egress models used to expand instantaneous counts of sport harvesters into all-day estimates of effort. $\overline{R}_t$ (the mean egress ratio) is the mean proportion of all-day effort expected to be present on the beach at time *t*. Time interval *t* is given in minutes relative to the local low tide.

The earliest "ingress curves" (dotted lines) were based on data collected almost exclusively during extreme low tides on weekends, when harvest activity was expected to be high. This matched the sampling frame for aerial surveys, which, prior to 1988, were also conducted almost exclusively during busy weekend low tides.

Expanding instantaneous harvester counts using these ingress models is relatively simple. As an example, consider the former clam ingress model used from 1996 through 2006 (Figure 7, black dashed line). The mean proportion of daily effort (i.e., the ingress ratio) at exactly low tide $\left(\overline{R}_0\right)$ is 0.28. To expand aerial survey counts, the count at time *t* is divided by the ingress ratio at time *t*. This is equivalent to multiplying by the inverse of the ingress ratio $\left(1 / \overline{R}_t\right)$. For example, if 15 harvesters were counted on a beach exactly at local low tide $\left(\overline{R}_0 = 0.28\right)$, the inverse of R_0 (i.e., the "expansion factor") would be 3.57, and the estimate of total harvesters on the beach over the entire day would be 15 x 3.57 = 53.55 harvesters. Due in part to insufficient sample size, variance was never estimated for points along the older ingress curves used prior to 2007.

A 1996 WDFW Biometric Review (Tagart et al.1996) stated that the current assumption of a "constant multiplier for all strata and all beaches may not be valid" and recommended repeating ingress studies from "time to time." Since publication of the Biometric Review, 517 new ingress/egress surveys were conducted, providing a total of 696 usable surveys on 39 different beaches, spanning a time-period from 1989 to 2005. Compared to the former model – which was based on 80 surveys at ten beaches surveyed in 1990 and 1992 – this accumulation of new and historic data represented a significantly expanded basis to test the assumption of a universally applicable "constant multiplier" (i.e., the effort expansion factor).

The terminology "ingress/egress" stems from the manner in which these data have been collected over time. Beginning in 2004, "ingress" surveys were replaced by "egress" surveys. Rather than counting harvesters as they entered (ingressed) the beach, surveyors in 2004 and thereafter were instructed to count clam and oyster harvesters seen leaving (egressing) the beach. The rationale was that counts of people *entering* a beach were more prone to error, since the surveyor would, in some cases, have to guess whether or not those people were actually going to engage in shellfish harvesting. People *leaving* the beach, on the other hand, could usually be positively identified as either harvesters or non-harvesters based on their observed activities. In practice, however, misidentification has probably only been a minor source of error. Harvesters, whether they are entering or leaving the beach, can normally be identified by their equipment (shovels, buckets, etc.). Also, the design of datasheets allowed surveyors to change counts if their initial determination that a person entering the beach was a shellfish harvester proved incorrect. For consistency, the term "egress" will be used in the remainder of this report rather than the more cumbersome "egress/ingress."

Two separate analyses are presented in the sections below. First, we evaluated the timing of flight counts to determine how many minutes from the time of local low tide harvester counts typically occurred given the structure of our aerial survey route. If flight counts consistently occurred close to the low tide, then analysis of egress data could be confined to the proportion of effort that occurs exactly at low tide. If this was not the case, then we needed to determine what time span of data should be analyzed. Second, we evaluated the egress data to determine if application of a "constant multiplier for all strata and all beaches" (Tagart et al. 1996) was valid, given the available data. If not, then we asked the question: Are there strata or groupings of beaches that will reduce the variance of the expansion factor and consequently the variance of effort estimates?

Timing of Flight Counts

Introduction

One possible option for analysis of available egress data was to simply assume that all flight counts occur consistently at low tide, or very close to low tide. Analysis could then be restricted to the proportion of effort that was observed at the time of the local low tide ($t = 0$). The primary purpose of this analysis, therefore, was to test the assumption that counts did not range broadly relative to low tide, and to suggest alternative strategies for analysis if warranted. More specifically, we posed the following questions:

1. Did flight counts on some beaches consistently occur as much as 30 minutes or more prior to (or after) low tide? If so, we would want to analyze egress data that included this extended window when flight observations actually occur. In the egress database, activity counts are recorded at 30-minute intervals. Of primary concern was the timing of flight counts on "actively managed" beaches as identified in regional Bivalve Plans.
2. Did flight counts for certain "groups" of beaches consistently occur significantly before or after the time of the local low tide? Such groupings may occur for a number of reasons, including geographic isolation or the structure of the aerial survey route. If groupings existed, we wanted to analyze egress data on those beaches separately.
3. Did the timing of flight counts vary in concert with extreme low tides and high recreational harvest activity? When beaches are crowded it is often necessary to slow down the airplane and conduct counts using more than one pass over the beach. This may have the effect of shifting the timing of flight counts. If so, then we wanted to consider the three established tide-day sampling strata (ELOW, HIGH and LOW) as a factor when analyzing egress data.

Methods

Data

Flight count data from 2004 and 2005 aerial surveys were analyzed. The reason for selecting 2004-2005 data was that the structure of the aerial survey route had remained relatively consistent over this time period, and was only slightly amended for 2006. Therefore, the timing of flight counts provided a reliable indicator of the range over which any future egress expansion factor would be applied.

Only observed sport harvest on public beaches was included in the final datasets. Two separate datasets were generated. The first included all available flight observations, while the second included only flight counts from actively managed beaches. All data, graphs, and computer code to conduct the analysis are available from the authors upon request.

Analysis

Analysis consisted of generating histograms and boxplots using the statistical program R. Histograms were examined to determine the distribution of flight counts relative to the time of local low tide at all beaches on the flight survey route. A separate set of histograms was generated for the core group of "actively managed" beaches. Boxplots were examined to identify quartiles and outlier values in the dataset, and to determine if there were significant differences in timing when the data were grouped by tide-day sampling strata.

Results

1) Histograms

Histograms (Figure 8, panel A) confirmed that flight counts often occurred more than 30 minutes from the time of local low tide. The left tail of the count distribution in Figure 8, panel A, indicates that several flight counts were recorded more than 60 minutes before the local low tide. All of these < -60 minute "early observation" counts occurred at beaches in Oakland Bay and Dyes Inlet.

On average, the Oakland Bay flight counts occurred 62 minutes prior to the published Shelton low tide ($N = 73$ flight counts), and the Dyes Inlet counts occurred 66 minutes prior to the published low tide at nearby Tracyton ($N = 3$ flight counts). The low sample size for Dyes Inlet was due to the fact that we did not fly over this area in 2004, and counts were only recorded when actual harvest activity was observed. Both sets of beaches are located at the end of long narrow channels that restrict the flow of an ebbing tide and effectively delay the time of the local low.

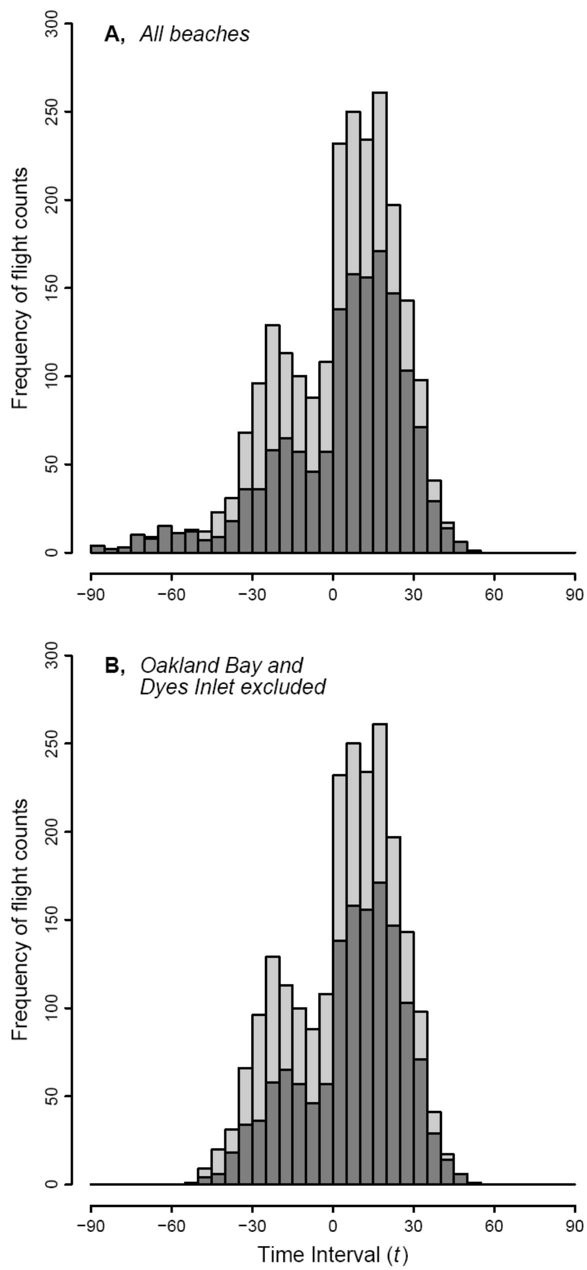

Figure 8. The frequency distribution of instantaneous aerial counts of sport harvesters on public beaches relative to local low tide (time interval *t* = 0). The light gray bars show frequency distributions from all beaches, the dark gray bars show frequency distributions for "actively managed" beaches. Data, in one-minute intervals, were obtained from aerial surveys in 2004-2005.

Although we have used the published NOAA tide corrections for Shelton in the egress database, based on recent observations we have found that the "true" local low tide at the Oakland Bay Ogg (BIDN 281043) actually occurs approximately 45 minutes after the Shelton low tide. This means that our flight counts at the most popular set of beaches in Oakland Bay occurred on average 107 minutes prior to the "true" local low tide. Preliminary data suggest that the "true" low at Silverdale Shoal in Dyes Inlet (BIDN 260540) may occur as much as 30 minutes after the published low tide at Tracyton .

When Oakland Bay and Dyes Inlet beaches were excluded from the flight count distribution (Figure 8, panel B), only 7.9 % of all observations were more than 30 minutes from local low tide, and there were no observations remaining more than 51 minutes from the local low tide.

Both histograms (Figure 8) display a bimodal distribution indicating that some beaches were regularly counted 10-30 minutes prior to low tide (the "early observation group"), while another set of beaches were normally counted 10-30 minutes after the low tide (the "late observation group"). The following set of beaches constituted the bulk of the early observation group: *South Indian Island County Park, P.T. Ship Canal East, Wolfe Property State Park, Shine Tidelands State Park, Kitsap Memorial State Park, Scenic Beach State Park,* and *North Bay.* We considered these beaches as candidates for possible inclusion in a distinct group when analyzing egress data. The late observation group consisted primarily of: *Fort Flagler State Park, Point Whitney Tidelands, Dosewallips State Park, Seal Rock FSC, Duckabush, Triton Cove Tidelands, Eagle Creek, Lilliwaup State Park, DNR-40, DNR 44-A W. Dewatto, Potlatch State Park, Twanoh State Park, Rendsland Creek, Quilcene Tidelands, Broad Spit, DNR-24, McMicken Island,* and *Frye Cove County Park.* Most members of the late observation group, however, were also frequently counted within ten minutes of the local low tide, so it was hard to argue that this latter group constituted a unique set of beaches that needed to be separately analyzed.

2) Boxplots

The first set of boxplots (Figure 9, panel A) shows the distribution of flight counts grouped by the three tide-day sampling strata (ELOW, LOW, and HIGH), and includes all available data. Again, all outlier values were from beaches in Oakland Bay and Dyes Inlet. Over 50% of the counts occurred within 20 minutes of the local low tide. The 95% CIs around group medians (indicated by notches within the gray boxes) ranged from 11.6 to 2.2 minutes for the HIGH and ELOW strata respectively. Surprisingly, counts occurred earliest in the ELOW stratum, contradicting our initial expectation that surveys would take longer on days when beaches were crowded with harvesters, and the plane might therefore have to circle or reduce speed to facilitate the counts.

The second set of boxplots (Figure 9, panel B) again shows the distribution of counts grouped by tide-day strata, but only includes data for "actively managed" beaches and excludes beaches in Oakland Bay and Dyes Inlet. Only minimal differences were evident between the three strata distributions. The confidence intervals of the medians overlapped, and the middle 50% of data spanned a nearly identical range of minutes across all three strata (~ -3 to +22 minutes).

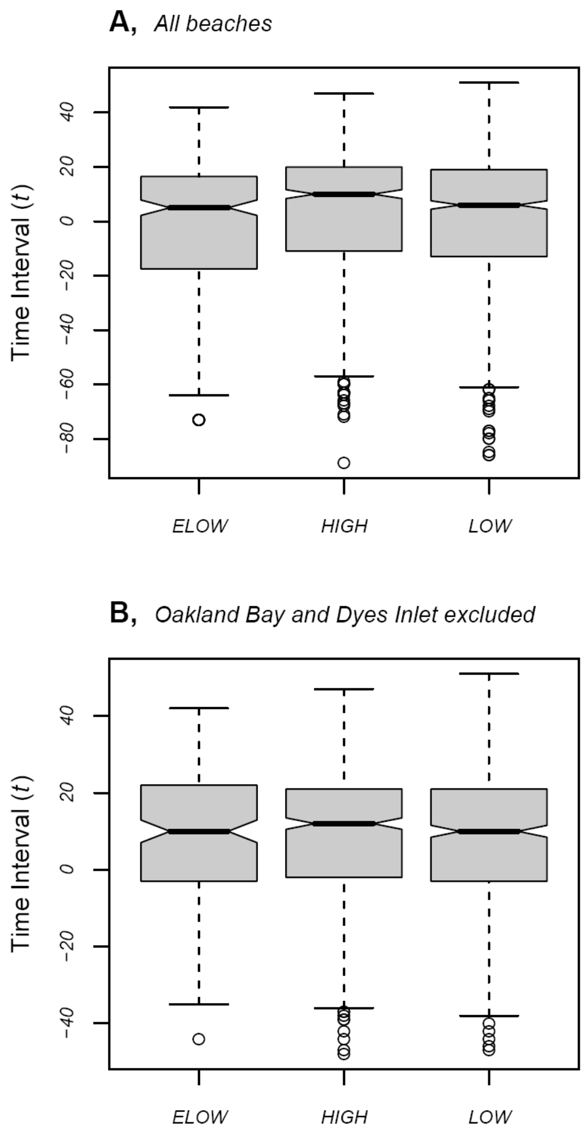

Figure 9. Boxplots showing the distribution of instantaneous aerial counts of sport harvesters on public beaches relative to local low tide (t = 0), grouped by the three tide-day strata used to stratify effort estimates. Panel A includes data from all beaches. Panel B includes only data from "actively managed" beaches and excludes Oakland Bay and Dyes Inlet. The horizontal line within each gray box denotes the median of the counts (i.e., the second quartile), and the notches represent the 95% confidence intervals around the median. The lower and upper edges of each box denote the first and third quartiles (the 25th and 75th percentiles, respectively). The dotted I-beams represent the range of counts not farther than 1.5 times the distance between quartiles. Counts falling outside this range are outliers, shown as open dots. Data, in one-minute intervals, were obtained from aerial surveys in 2004-2005.

3) Summary of Flight Count Timing Analysis

Results confirmed that flight counts consistently occurred within one hour of low tide on all beaches except those in Oakland Bay and Dyes Inlet. When these beaches were removed, approximately 92% of all flight counts occurred within 30 minutes of the local low tide. A subset of “early observation group” beaches was identified where counts normally occurred 10-30 minutes prior to the low tide. Maximum and minimum values within this early observation group ranged from 48 minutes before the low tide to eight minutes after the low tide. Another less cohesive set of beaches was identified where counts normally occurred 10-30 minutes after the low tide. Counts on beaches in Oakland Bay and Dyes Inlet occurred on average 62 and 66 minutes before the low tide, respectively. Given the relatively wide range in timing of flight counts (Figure 8), it was determined that data spanning a full hour on either side of low tide should be used in the analysis of egress survey data.

There was insufficient evidence to conclude that the three tide-day strata (ELOW, LOW and HIGH) were a factor in how the timing of flight counts was distributed. It was originally suspected that the need for the plane to slow down and circle popular beaches on extreme low weekend/holiday tides would affect the timing of observation. However, this proved not to be the case. In fact, counts within the ELOW stratum occurred slightly earlier with respect to low tide, on average, than counts within the HIGH and LOW strata.

The timing of flight counts at beaches in Oakland Bay and Dyes Inlet presents a unique set of questions. For Oakland Bay it would be advisable to carefully examine all available egress data to determine if flight counts at this beach need to be multiplied by a separate set of expansion factors. For Dyes Inlet, where the number of egress surveys is extremely low, new data will be required to determine appropriate expansion factors. We currently survey three actively managed beaches in Dyes Inlet, but do not have egress data for any of these. In addition, Silverdale Shoal only emerges briefly on minus tides. It is probable that by surveying this beach 66 minutes before the low tide (as currently occurs with the present flight route) we regularly arrive before any usable clam habitat is above water. If these Dyes Inlet beaches are to remain actively managed, obtaining egress surveys and mapping Silverdale Shoal to determine the extent of exposed beach at various tide heights must be considered priority tasks for future field seasons.

Egress Survey Analysis

Introduction

The two models formerly used to expand harvester counts on clam and oyster beaches from 1996 through 2006 were derived from a small sampling of 80 surveys at ten beaches conducted in 1990 and 1992. Due to inadequate sample size it was not previously possible to determine if application of a "constant multiplier for all strata and all beaches" (Tagart et al. 1996) was valid, or to calculate variance for points along the egress curves. The latter deficiency long prevented the calculation of 95% confidence intervals on both sport effort and catch estimates. In the sections below we used an expanded egress database consisting of 696 surveys conducted at 39 beaches between 1989 and 2005 to formulate new egress models. The aim was to identify strata or groupings of beaches that would minimize the variance of the egress expansion factors. We also proposed alternate methods to calculate variance for points along the egress curve. Specifically, we posed the following questions:

1. Does stratification of egress expansion factors using the existing tide-day sampling strata (ELOW, HIGH and LOW), or some combination of these strata, improve the precision of estimates?
2. Does stratification of egress expansion factors based on the status of a given beach as an "oyster beach" (i.e., a beach where sport effort is directed almost entirely at Pacific oysters) or "clam beach" improve the precision of estimates? From 1996 through 2006, we used separate clam and oyster egress models to expand harvester counts.
3. Have egress curves changed over time, or has harvester behavior remained relatively constant in terms of when harvesters are present during any given tide cycle?
4. Does the shape of egress curves on any given beach or set of beaches suggest stratification opportunities? For example, do harvesters consistently arrive earlier or later on particular beaches, as evidenced by early or late peaks in the egress curves?
5. Do beaches isolated at the end of narrow inlet channels, where the low tide is delayed by one or two hours beyond the published low tide – as in Dyes Inlet or Oakland Bay – require separate sets of expansion factors?
6. Once appropriate egress models are defined, what is the best method to calculate variance for points along each egress curve? Egress curves are based on discrete "activity counts" observed by the surveyors at 30-minute intervals, but harvester counts are recorded by aerial observers on a continuous scale at a resolution of one minute throughout the course of the flight route. Should variance be estimated at one-minute increments along the egress curve using a smoothed egress model, or should a step function be used with variance estimates calculated for each 30-minute increment. The former method would provide variance estimates for *each* minute during the 4-hr period straddling low tide. The latter method would provide only *one* variance estimate for *all* counts recorded within 30 minutes of low tide, and *one* variance estimate for each successive 30-minute time-span on either side of low tide.

Methods

Data

Egress surveys have been conducted at Puget Sound public beaches since 1970. The earliest surveys were five hours in duration. Harvesters were counted as they entered the beach, and instantaneous "activity counts" of harvesters present on the beach were made at 30-minute intervals. From 1976 through 1988 a variety of different survey methods were employed. The duration of surveys ranged anywhere from 2.5 to 8 hours, while activity counts continued to be recorded every 30 minutes. Most of these early surveys were conducted during extreme low tides on weekends (i.e., within the ELOW stratum). It was not until 1989 that surveys were standardized to six hours in total length and regularly included weekdays and higher tide strata. A brief description of all available egress data collected since 1970 is included in Appendix 1. Also included in Appendix 1 are examples of data sheets and original instructions detailing how to conduct the surveys.

To ensure that all data included in the final analysis dataset were obtained using comparable methods, only surveys from 1989 to 2005 were included. However, three notable changes in methods over this time period need to be mentioned:

1. While surveys over a majority of years were six hours in duration, those conducted from 1998 through 2001 were only four hours in duration. During this period, managers apparently felt that virtually all sport harvesters using the beaches would be likely to be observed and recorded in the shorter 4-hr survey. Thus, it was assumed from 1998 through 2001 that a 4-hr survey would provide as reliable an estimate of H_s (Equation 33) as a 6-hr survey. We tested this assumption with egress data in the analysis below.
2. Prior to 1998 harvesters were counted as they entered ("ingressed") the beach. From 1998 through 2001, harvesters were counted both entering and leaving the beach; ideally, of course, the two counts should be identical. Beginning in 2004, harvesters were only counted as they exited ("egressed") the beach.
3. Prior to 2004, egress counts included all "shellfish harvesters." Written instructions (Appendix 1) confirm that this count included intertidal crab harvesters. Beginning in 2004 surveyors were verbally instructed to count only clam and oyster harvesters, although in some cases datasheets suggest that crabbers may have been included in the count. The actual definition of "harvester" was not explicitly stated in the written egress survey instructions.

We first tested the assumption that 4-hr egress surveys conducted from 1998 through 2001 provided counts of all-day harvester effort that were comparable to those made during 6-hr egress surveys. We tested this assumption by posing the question: If we had started all our 6-hr egress surveys one hour later, and ended the surveys one hour earlier, would we have missed counting a significant number of harvesters? To answer this question, we compared two data sets: **(1)** the original harvester counts from all 6-hr egress surveys, and **(2)** the harvester counts from the same 6-hr egress surveys, but truncated to exclude counts from the first and last hour of each 6-hr survey. We tested the following null and alternative hypotheses with a paired-sample *t*-test:

$\boldsymbol{H_0}$**:** $\mu_d = 0$
$\boldsymbol{H_A}$**:** $\mu_d > 0$

Where μ_d is the mean population difference between the 6-hr counts and the truncated 4-hr counts. Note that the test is one-tailed since it is impossible for a count from a 6-hr survey to be less than the paired count from the same survey truncated to four hours.

Results of the paired *t*-test showed a highly significant difference between the 6-hr and 4-hr counts ($t = 10.67$, $t_{0.05(1),\,313} = 1.65$, P (one-tailed) = 3.55×10^{-23}, $n = 314$, $df = 313$). We concluded that the change to 4-hr surveys from 1998 to 2001 likely resulted in significant under-counting of all-day harvesters. That is, a significant number of harvesters probably came to beaches and left them during the 1-hr period prior to the start of the 4-hr surveys, while others probably entered the beach after the 4-hr surveys were concluded. Consequently, to use these 4-hr survey data for analysis it was first necessary to apply a correction factor. The method suggested by Bob Conrad (Quantitative Services Manager, Northwest Indian Fisheries Commission) consisted of calculating a ratio between 6-hr and 4-hr egress sums, using the same two data sets from the paired-sample analysis above. Using all available 6-hr surveys, the egress correction ratio for 4-hr surveys was calculated as:

$$C_e = \frac{\sum E_6}{\sum E_4} \qquad (35)$$

where

C_e = the egress correction ratio
E_6 = all egress counts over the full six hours.
E_4 = egress counts for the same set of surveys as above, but truncated to only include counts spanning the four hours centered on low tide.

The resulting egress correction factor ($C_e = 1.12648$) was used to expand all total harvester counts (H_s from Equation 33) from the 4-hr surveys. For example, on May 4th 1999, at Potlatch State Park, a total of 38 harvesters were counted entering and using the beach during the entire 4-hr ingress survey. Multiplying 38 by the correction factor of 1.12648 produced a corrected count of 42.806 harvesters; this is the total number of harvesters that we expect would have been counted entering and using the beach had the egress survey been conducted for six hours rather than four hours. This correction factor effectively adjusted the 4-hr surveys so that egress counts would not be underestimated.

No correction was necessary for the change from "ingress" to "egress" surveys. During years when both counts were available (i.e., when harvesters were counted both entering and leaving the beach) and in those instances when the two resulting counts were not identical, the "egress" counts were used if ancillary data in the original datasheets were insufficient to resolve the difference. If harvesters were present on the beach prior to the survey, they were added to *ingress* counts. If harvesters were still on the beach at the end of the survey they were added to the *egress* counts.

No correction was possible to adjust for the inclusion of intertidal crab harvesters in egress totals gathered prior to 2004. Once an individual has been identified as a "shellfish harvester" in egress or ingress counts, it is either difficult (given sufficient ancillary data) or impossible (given multiple half-hour activity counts with crabbers present) to adjust counts to include only clam and oyster harvesters. The inclusion of crabbers in egress counts prior to 2004 therefore represents a small but systematic bias in this analysis. By slightly inflating the total number of clam and oyster harvesters, the addition of crabbers results in smaller egress ratios (R_t from Equation 33) and consequently higher effort expansion factors.

The data section in Appendix 1 lists SAS programs that were used to proof data for each year that surveys were conducted. Programs were commented to detail proofing methods and to list some of the data errors that were subsequently corrected. The most common error encountered was failure to calculate the correct time of local low tide. In cases where an erroneous time for local low tide was used, all data for that day were shifted to the nearest 30-minute interval. If data had to be shifted by more than 30 minutes, the surveys were truncated to four hours. Surveys were rejected if any egress counts were missing, or if more than one 30-minute activity count was missing. Only egress surveys from Bivalve Regions 1, 5, 6, 7 and 8 were used in the analysis, and no surveys conducted during winter or on plus tides (> 2.0 ft) were included.

Analysis

Analysis of the egress data proceeded as follows:

1. Egress ratios (R_t from Equation 33) were generated for each 30-minute time increment of each survey in the database. This ratio, equivalent to the proportion of all-day harvester effort present at each time interval during the tide cycle, served as the primary analysis variable. The resulting proportions were examined using histograms and quantile plots to determine if the data were normally distributed, and hence suitable to be analyzed using

parametric methods. Additional graphical summaries were generated to examine distributions on both aggregate and beach-specific levels.
2. The three tide-day strata (ELOW, LOW and HIGH) and the two "clam beach/oyster beach" strata identified in the *Introduction* to this section were tested by generating confidence intervals around group means at each 30-minute time interval. Candidate strata were rejected if 95% confidence intervals consistently overlapped. Next, the "shapes" of beach-specific egress curves were tested to determine if additional stratification opportunities existed. Shapes were categorized by two criteria: slope and elevation. It was assumed that egress data for beaches with higher peaks at low tide would also exhibit greater overall curvature. Candidate strata were tested using the same overlapping confidence interval method described above.
3. Data from Oakland Bay were plotted to determine if the proportion of all-day harvester effort was symmetric about low tide, and whether these data needed to be treated as unique, given the offset in timing of aerial surveys relative to the time of local low tide (described in the previous section *Timing of Flight Counts*).
4. Two alternate scenarios for calculating variance at points along the egress curve were proposed and compared. The first method consisted of treating the egress curve as a step-function with variance estimates at each 30-minute interval. The second method used an interpolating spline function to generate variance estimates at one-minute intervals along the egress curves.

All analyses and graphs were generated using the R statistical program. Code for all analyses and graphs are available from the authors.

Results

1) Data distribution

Histograms and quantile plots of the egress data are shown in Figure 10. The predominance of zero values in the dataset is evident in panel A. Given that relatively few harvesters arrive at a beach more than one hour before low tide, this result was expected. The quantile plot in Figure 10, panel B, strongly suggested that these data should not be considered as normally distributed.

When zero values were removed, other prominent modes in the data became apparent. Modes at R_t = 1.0 and 0.8877 resulted from situations when the all-day harvester egress total (H_s) was equal to the half-hour activity count (H_t) for 6-hr and 4-hr surveys respectively. This situation occurred whenever all the harvesters present during the entire survey happened to be present during a half-hour activity count. The difference in the two values stemmed from the fact that 4-hr surveys were expanded by a correction factor of 1.12648 prior to calculating proportions. Similarly, the remaining mode at R_t = 0.4438 resulted from situations where the activity count represented half the all-day harvester egress total during 4-hr surveys. Again, the quantile plot in Figure 10, panel D, suggested that the data were not normally distributed.

The same modes and skewed distributions evident in Figure 10 are also evident in Figure 11. This figure shows the distribution of all-day effort proportions (R_t) at each time interval when data from all surveys were combined. Proportions are indicated by semi-transparent gray diamonds. Darker regions indicate a higher density of data points resulting from the characters being superimposed. Data values at each time interval were skewed towards the higher proportions, and modes at R_t = 0.0, 0.8877, and 1.0 are evident. The overall egress curve, however, was symmetric about low tide. Here the mean is indicated as a black dashed line, and the median is shown as a dotted line.

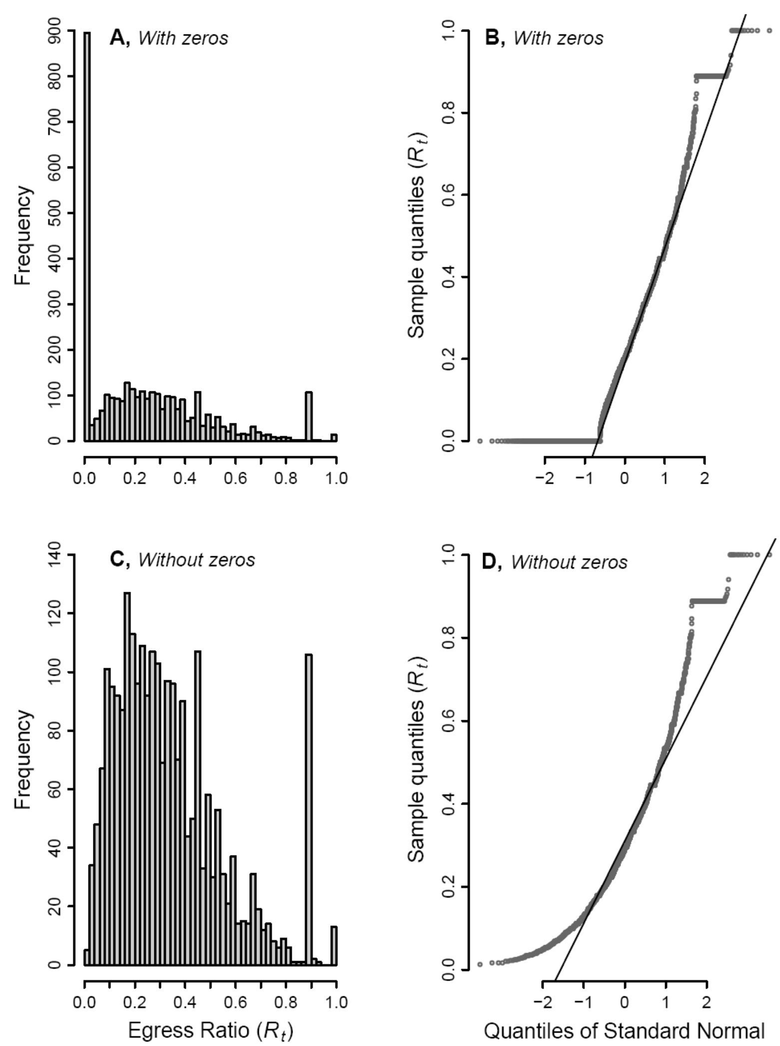

Figure 10. The frequency distribution and quantile plot of all individual half-hour egress ratios (R_t) from all egress surveys conducted during 1989-2005. The straight lines in panels B and D are plotted through the first and third quartiles to assess the linear fit of the sample (R_t) distribution.

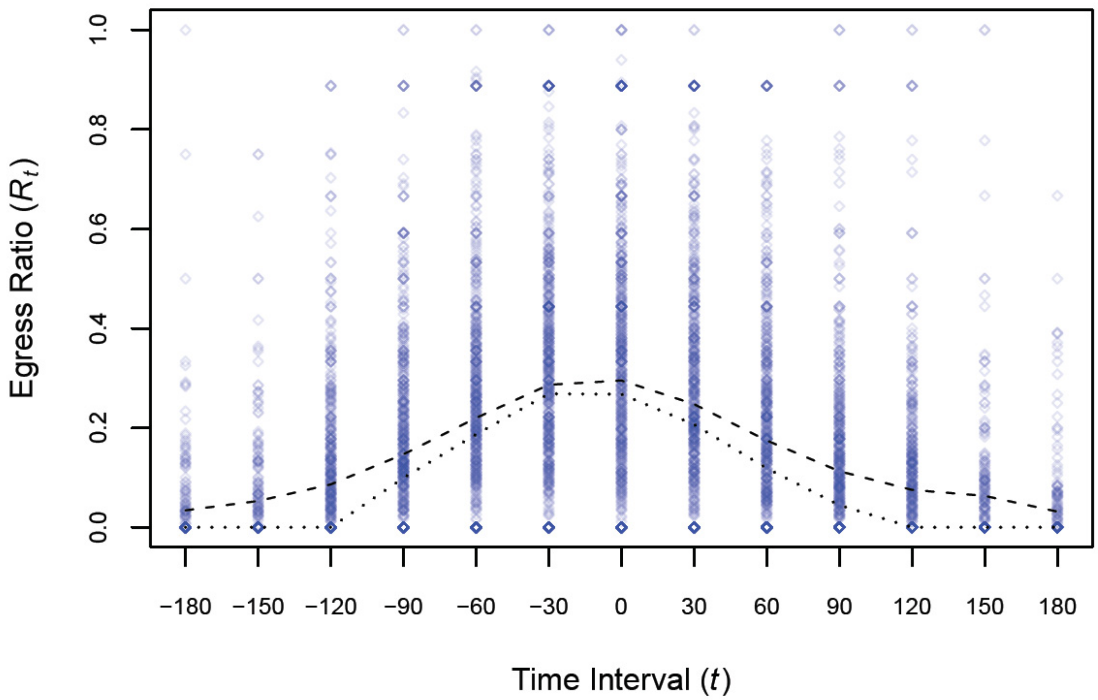

Figure 11. The distribution of all individual half-hour egress ratios (R_t), grouped by time intervals. Data from all egress surveys conducted during 1989-2005. Individual egress ratios are shown as semi-transparent diamonds. Darker regions represent overlapping data points. The dashed line indicates the mean R_t for each time interval ($\overline{R_t}$), and the dotted line indicates the median R_t for each time interval.

Beach-specific graphs of all available egress surveys are shown in Figure 12. Again the data are shown in semi-transparent gray to highlight density. Time intervals were limited to the 2-hr period centered on low tide identified as the appropriate analysis subset in *Timing of Flight Counts*. The high variability evident in these graphs was exacerbated by inclusion of surveys where only one or two harvesters were counted all day. When surveys were limited to include only those where the all-day egress total was > 15 harvesters, much of this variability disappeared (Figure 13), and beach-specific harvester behavior was easier to discern. The most prominent example of atypical harvester behavior was P.T. Ship Canal East, where a majority of harvesters consistently arrived at least 30 minutes prior to the low tide.

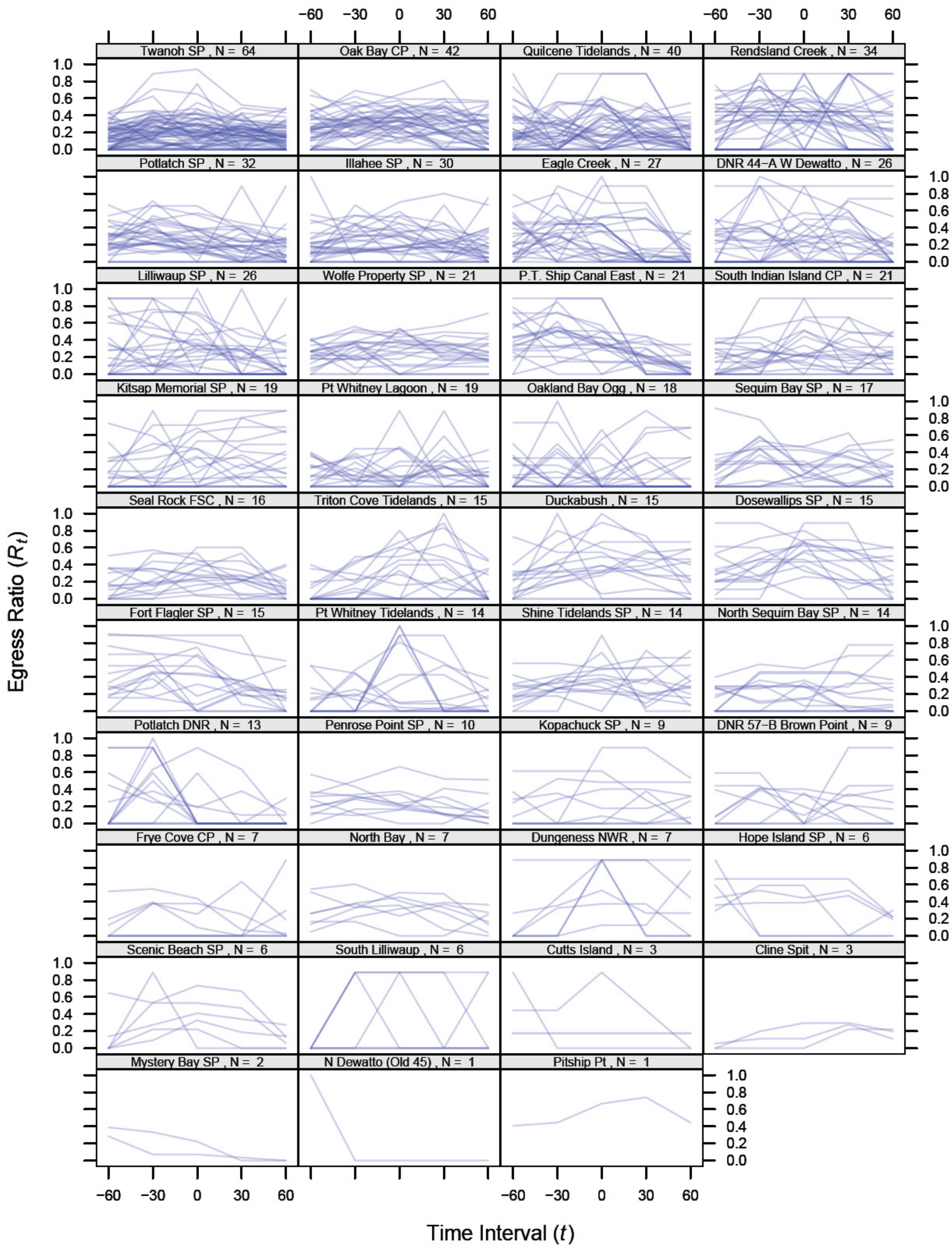

Figure 12. The distribution of all individual half-hour egress ratios (R_t) by beach. The number of egress surveys (N) is given above each graph. Data from all egress surveys conducted during 1989-2005. Data are shown only for time intervals between –60 and 60 minutes.

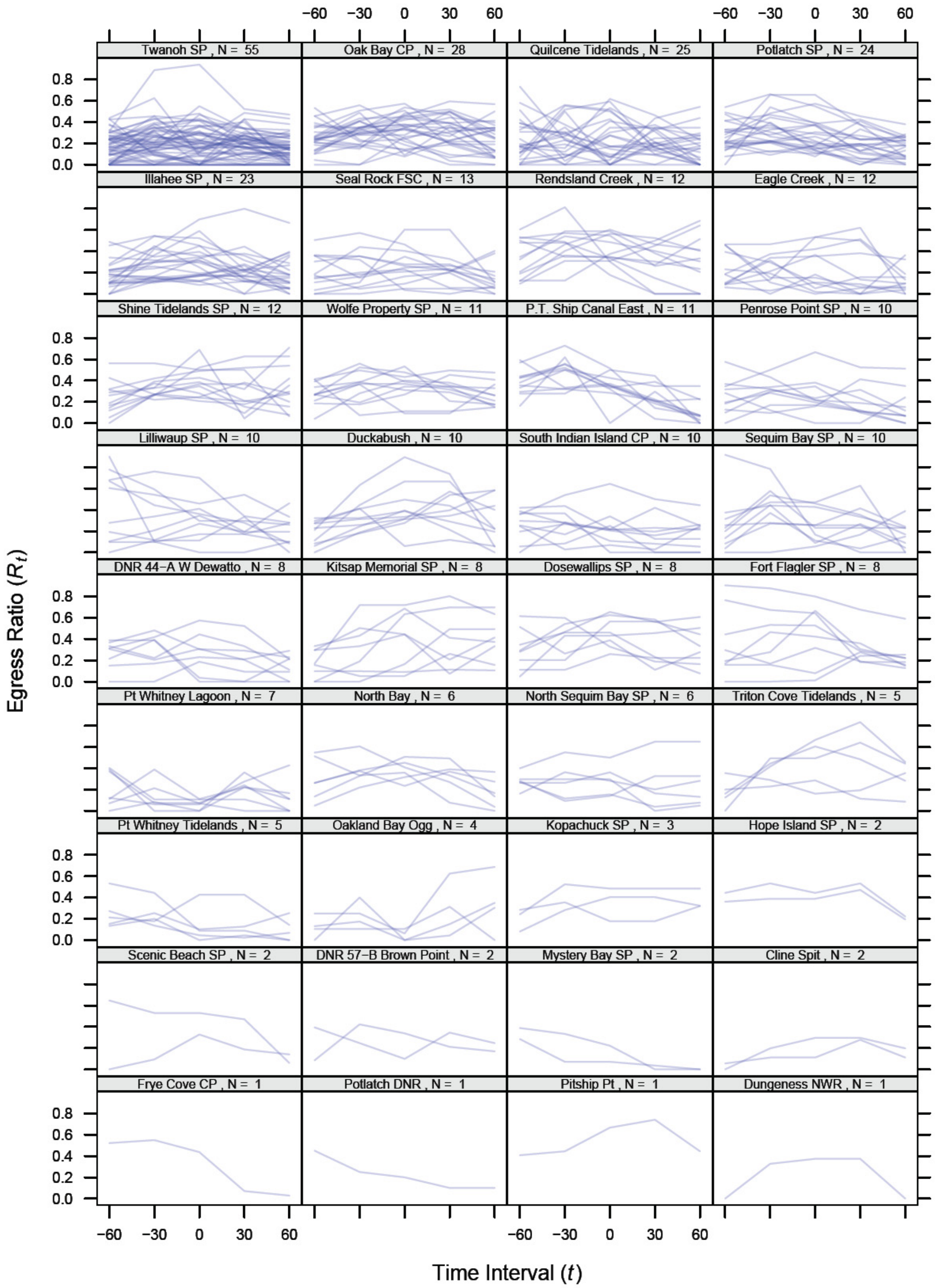

Figure 13. The distribution of all individual half-hour egress ratios (R_t) from egress surveys in which > 15 harvesters were counted all day. The number of applicable egress surveys (N) is given above each graph. Data from egress surveys conducted during 1989-2005.

Evidence for beach-specific harvester behavior was more clearly displayed by plotting the mean and median R_t values for each time interval. In Figure 14, the mean R_t (i.e., $\overline{R_t}$) was plotted as a black solid line and the median R_t as a gray dashed line.

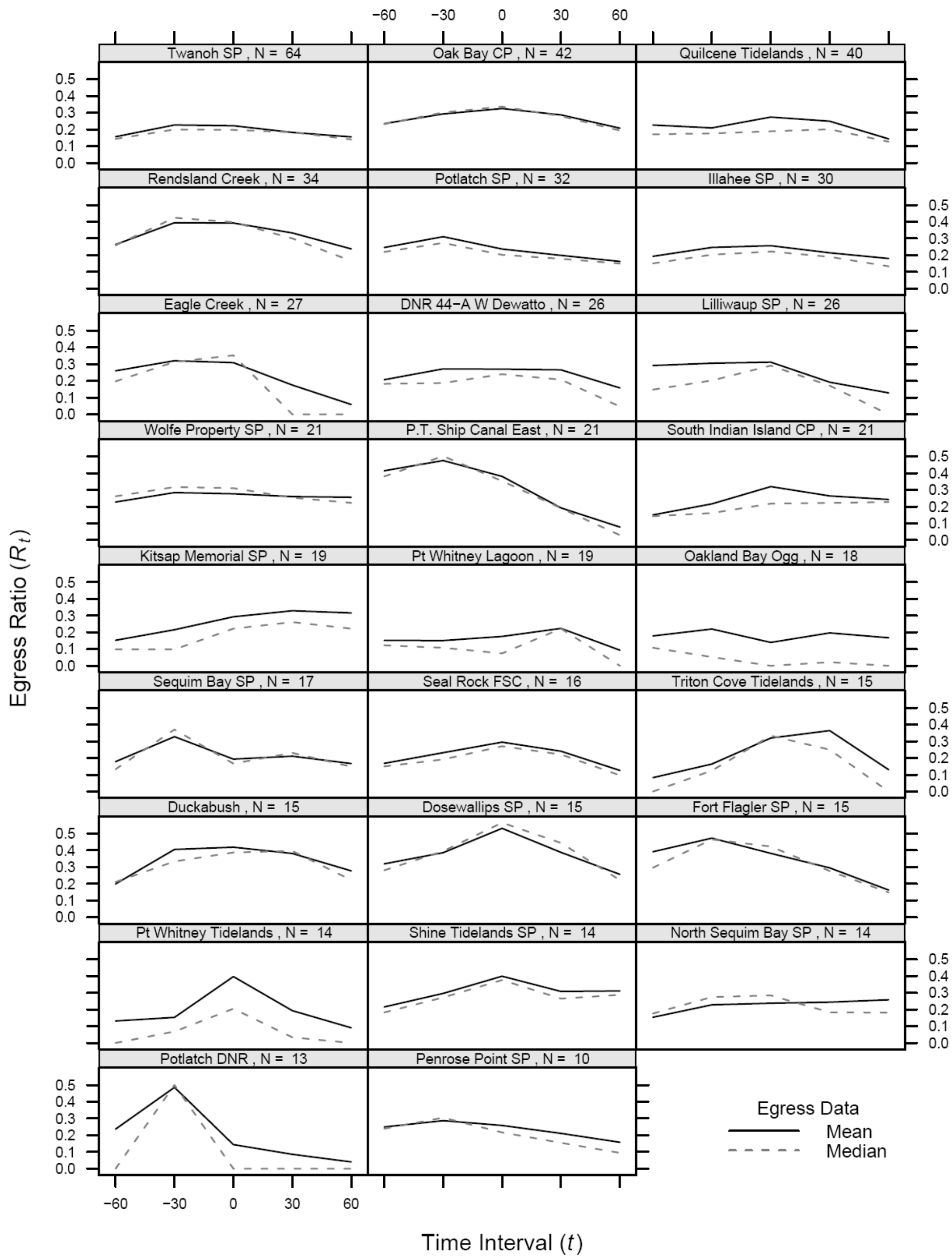

Figure 14. The mean and median values of half-hour egress ratios (R_t) by beach. The mean R_t for each time interval ($\overline{R_t}$) is shown as a solid line. The median R_t for each time interval is shown as a dashed line. Only beaches where at least ten egress surveys were conducted are shown. The number of applicable egress surveys (N) is given above each graph. Data from egress surveys conducted during 1989-2005, including those in which only one harvester was counted all day.

Only beaches where at least ten surveys were conducted were included in Figure 14, but all surveys, even those where only one harvester was counted all day, were included. Again, P.T. Ship Canal East showed a prominent peak of harvester effort 30 minutes prior to the low tide, followed by a steep decline. A similar pattern was evident at Fort Flagler State Park. By contrast, most harvesters appeared to arrive *after* the low tide at Kitsap Memorial State Park and South Indian Island County Park. Other beaches, such as Twanoh and Illahee State Parks, and Oak Bay County Park, exhibited more symmetric egress curves.

Egress curves at beaches typically observed 10-30 minutes prior to low tide (i.e., the "early observation group" of beaches identified in the previous section *Timing of Flight Counts*: South Indian Island County Park, P.T. Ship Canal East, Wolfe Property State Park, Shine Tidelands State Park, Kitsap Memorial State Park, Scenic Beach State Park, and North Bay) did not exhibit any consistent pattern of harvester behavior (Figure 14). Curves at South Indian Island County Park and Kitsap Memorial State Park both had positive slopes. By contrast, there was a strong negative slope at P.T. Ship Canal East, and relatively flat curves at Wolfe Property State Park and North Bay. There was no indication of any consistent egress patterns that would suggest analyzing these "early observation" beaches as a distinct group.

2) Stratification tests

Due to non-normal distribution of the egress data, bootstrap resampling was used to derive 95% confidence intervals (CIs) of $\overline{R}_t$ (the mean egress ratio) for candidate strata groupings. CIs around $\overline{R}_t$ were calculated for each 30-minute time interval, and were derived using 10,000 bootstrap samples. When CIs overlapped for two or more candidate strata, we assumed that there was no statistically significant difference between the strata.

The R function *smean.cl.boot* was used to generate bootstrap CIs. This function uses the Type 7 method outlined in Hyndman and Fan (1996) to compute quantiles, with the formula given as:

$$p(k) = (k-1)/(n-1) \tag{36}$$

where

p = probability
k = the number of ordered samples falling outside the range specified by p
n = the total number of samples

For example, the lower limit of a 95% CI (CI_{low}), derived from n = 10,001 bootstrap samples, would be given by, k = 501 since $p(k)$ = (501-1)/10,001-1) = 0.05. Therefore, CI_{low} would be represented by the 501st ordered value in the sample range.

2.1) Tide-day Strata

Results for the overlapping CI analyses of tide-day strata are shown in Figures 15 and 16. The first test (Figure 15) compared all three strata: ELOW, HIGH and LOW. Mean values of R_t (i.e., $\overline{R}_t$) were clearly higher for the ELOW strata, but the 95% CIs of the ELOW and LOW strata overlapped at each interval within 30 minutes of low tide. There was no significant difference between CIs for the LOW versus HIGH strata.

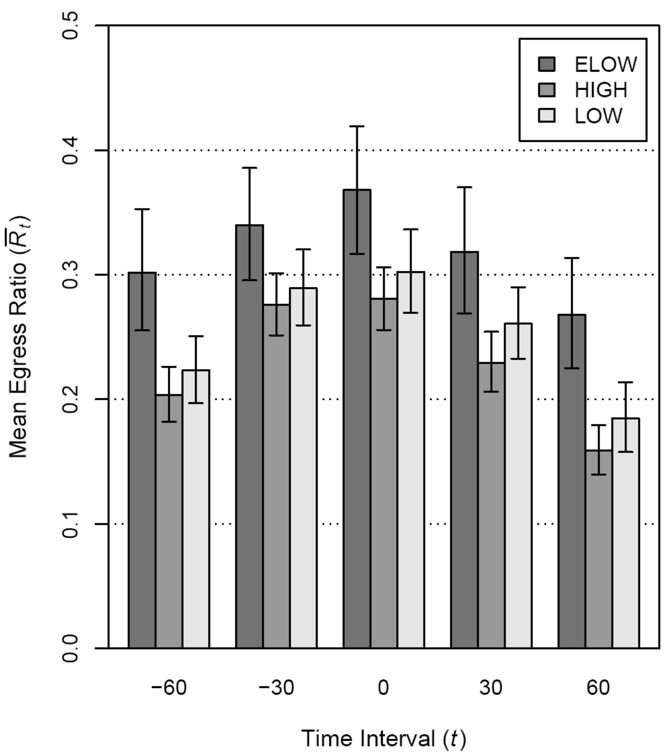

Figure 15. The mean egress ratio for each time interval ($\overline{R}_t$), grouped by the three tide-day strata used in effort estimation (ELOW, HIGH, and LOW). The mean egress ratio ($\overline{R}_t$) for each time interval *t* is indicated by the top of each bar. Bootstrap 95% confidence intervals surrounding the means are indicated by solid black I-beams. Data from egress surveys conducted during 1989-2005.

Given the large volume of data available for comparisons, a second set of 95% CIs was derived assuming a normal distribution. The R function *plotmeans* was used to generate parametric CIs. A comparison between CIs generated using the two methods (bootstrap and parametric) are shown in Table 8. There was little difference between the two methods; divergence was confined to the third decimal place in each case. Thus, analysis of both bootstrap and parametric CIs showed the same pattern of overlapping CIs when the three tide-day strata (ELOW, HIGH and LOW) were compared.

Table 8. A comparison between normal parametric and bootstrap non-parametric 95% confidence intervals (CI) around the mean egress ratio ($\overline{R_t}$) by time interval and tide-day stratum. Bootstrap results were derived using the R function smean.cl.boot.

		Bootstrap (n = 10,000)			*Parametric*		*Difference*	
Time Interval	**Stratum**	**Mean**	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**	**Upper**
-60	ELOW	0.3019	0.2533	0.3530	0.2512	0.3526	0.002	0.000
-60	HIGH	0.2037	0.1816	0.2265	0.1814	0.2260	0.000	0.000
-60	LOW	0.2233	0.1967	0.2506	0.1961	0.2505	0.001	0.000
-30	ELOW	0.3399	0.2962	0.3837	0.2942	0.3857	0.002	-0.002
-30	HIGH	0.2760	0.2519	0.3013	0.2511	0.3009	0.001	0.000
-30	LOW	0.2891	0.2590	0.3196	0.2583	0.3199	0.001	0.000
0	ELOW	0.3681	0.3164	0.4198	0.3157	0.4205	0.001	-0.001
0	HIGH	0.2807	0.2562	0.3067	0.2552	0.3062	0.001	0.001
0	LOW	0.3023	0.2700	0.3366	0.2686	0.3361	0.001	0.001
30	ELOW	0.3185	0.2696	0.3700	0.2663	0.3706	0.003	-0.001
30	HIGH	0.2294	0.2059	0.2534	0.2054	0.2534	0.001	0.000
30	LOW	0.2607	0.2310	0.2912	0.2308	0.2906	0.000	0.001
60	ELOW	0.2680	0.2253	0.3135	0.2229	0.3131	0.002	0.000
60	HIGH	0.1590	0.1396	0.1799	0.1389	0.1791	0.001	0.001
60	LOW	0.1846	0.1569	0.2125	0.1565	0.2126	0.000	0.000

When ELOW strata were compared to non-ELOW strata (i.e., the HIGH and LOW strata combined), however, significant differences (in terms of overlapping CIs) were identified at all but one time interval (Figure 16). A small overlap between CIs was evident at -30 minutes. Given higher sample size in the ELOW category, it would be reasonable to expect that *all* time intervals would exhibit significant differences. Results of this analysis therefore suggested that the ELOW and non-ELOW categories could be useful stratification variables.

2.2) Oyster Beach versus Clam Beach Strata

From 1996 through 2006 the only variable used to stratify egress models was designation as a "clam" or "oyster" beach. The three beaches designated as "oyster beaches" for effort expansion purposes were: Twanoh State Park, Lilliwaup State Park and Seal Rock FSC. All other public beaches in Bivalve Regions 1, 5, 6, 7 and 8 were considered "clam beaches" for effort expansion purposes. Inspection of creel survey data, however, suggested that we should also include Scenic Beach State Park as a candidate in the oyster beach group for this analysis. Results of overlapping-CI comparisons to determine if clam beach and oyster beach strata should be retained are shown in Figure 17. Although mean egress ratios ($\overline{R_t}$) at all time intervals were higher for clam beaches when the original set of three oyster beaches were tested, the differences were mostly non-significant based on overlapping 95% CIs. Only at the +30-minute interval was there separation between CIs. When Scenic Beach State Park was included in this group (Figure 17, panel A) the result was essentially identical.

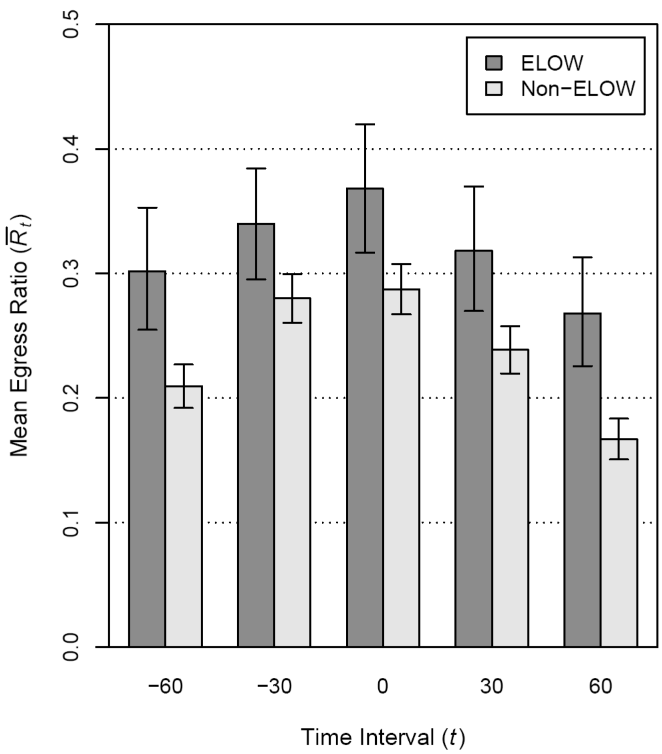

Figure 16. The mean egress ratio for each time interval ($\overline{R}_t$), grouped by the ELOW stratum and the non-ELOW strata (i.e., the combined data from the HIGH and LOW strata). The mean egress ratio ($\overline{R}_t$) for each time interval *t* is indicated by the top of each bar. Bootstrap 95% confidence intervals surrounding the means are indicated by solid black I-beams. Data from egress surveys conducted during 1989-2005.

The beach-specific graphs in Figure 14 suggested that any perceived difference in egress ratios between oyster and clam beaches were driven exclusively by surveys conducted at Twanoh State Park. When this beach was excluded (Figure 17, panel B), there were no significant differences remaining between egress ratios at clam and oyster beaches. By contrast, when Twanoh State Park was isolated and compared against all other beaches there were significant differences identified at every time interval except +60 minutes (Figure 17, panel C). Given the timing of flight counts, the result at +60 minutes could probably be ignored, since only 4.8% of all aerial survey counts at Twanoh State Park occurred more than 45 minutes after low tide in 2004 and 2005 (Figure 17, panel D). These results suggest that a separate egress model could be used to expand flight counts at Twanoh State Park, especially given the high number of egress surveys (n = 64).

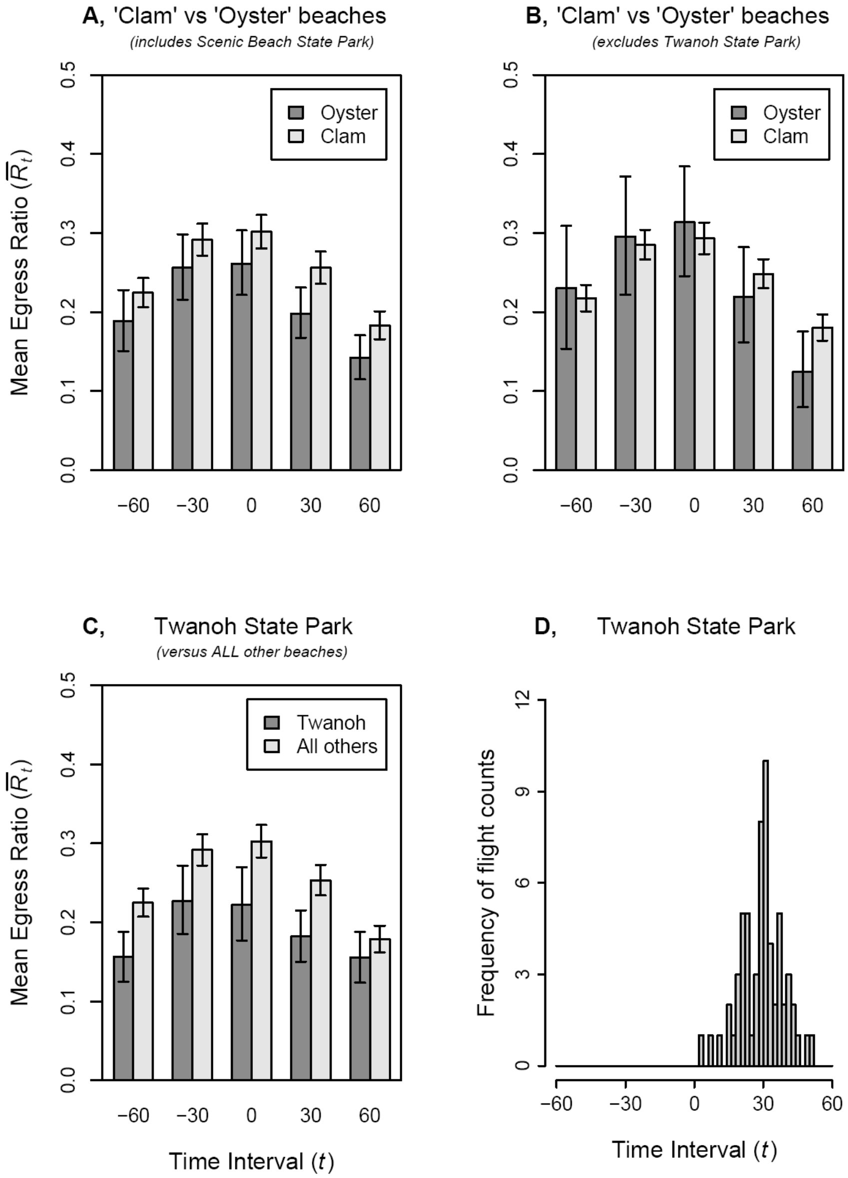

Figure 17. The mean egress ratio for each time interval ($\overline{R_t}$) by former beach types (i.e., the former "clam" and "oyster" beaches). The frequency distribution of instantaneous aerial flight counts at Twanoh State Park (formerly an "oyster beach") is shown in panel D. Counts, at one-minute intervals, were obtained from aerial surveys in 2004-2005. The mean egress ratio ($\overline{R_t}$) for each time interval *t* is indicated by the top of each bar in panels A - C. Bootstrap 95% confidence intervals surrounding the means are indicated by solid black I-beams. Data from egress surveys conducted during 1989-2005.

2.3) Egress curves over time

To determine if harvester behavior had changed over time, egress data were categorized by three eras, with boundaries set at 1997, 2002, and 2005. These boundaries also correspond to major shifts in the way egress surveys were conducted, as outlined above. Results indicated that there were no significant differences in the egress curves when CIs of mean egress ratios were compared between eras (Figure 18). Also, there were no discernible trends to warrant further investigation.

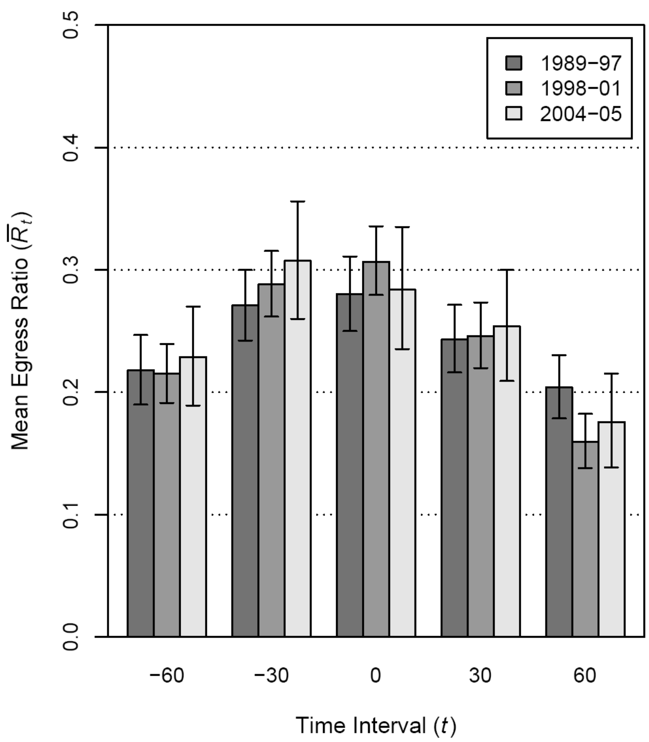

Figure 18. The mean egress ratio for each time interval ($\overline{R_t}$) by era. The mean egress ratio ($\overline{R_t}$) for each time interval *t* is indicated by the top of each bar. Bootstrap 95% confidence intervals surrounding the means are indicated by solid black I-beams. Data from egress surveys conducted during 1989-2005.

2.4) Egress data slopes

To objectively identify slopes in the egress data that would indicate whether harvesters consistently arrived prior to, or after the local low tide, a linear regression line was fitted to data from each beach. The slopes were tested for significance at the $\alpha = 0.05$ level. Beach-specific results are shown in Figure 19. The number of surveys (N) and probabilities of slope significance (p) associated with each beach are reported. Six beaches exhibiting statistically significant negative slopes were identified as Early Peak beaches: Potlatch State Park, Potlatch DNR, Eagle Creek, P.T. Ship Canal East, Fort Flagler State Park, and Lilliwaup State Park. One beach with a statistically significant *positive* slope (Kitsap Memorial State Park) was identified as a "late peak" beach.

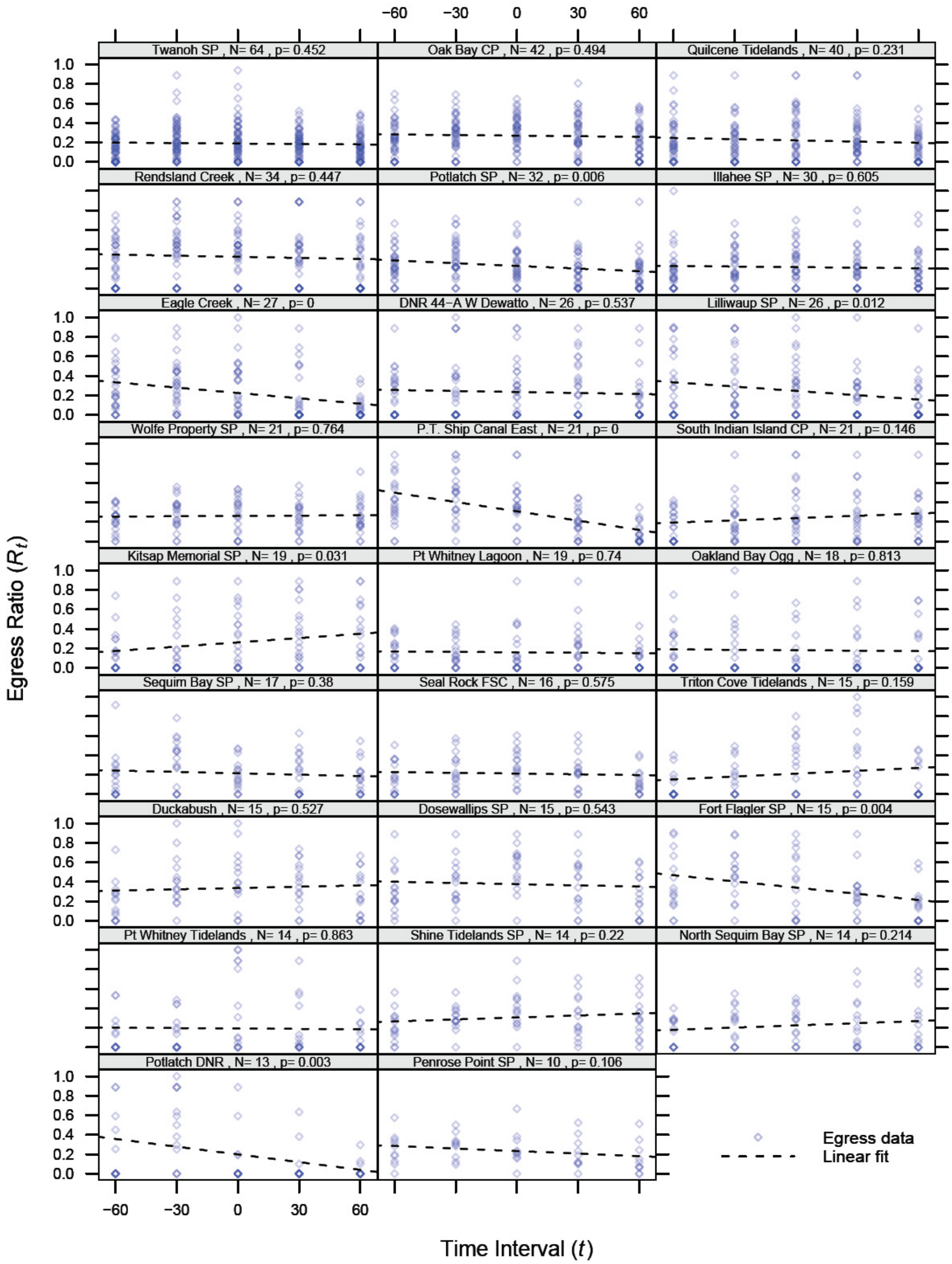

Figure 19. The distribution of all individual half-hour egress ratios (R_t) by beach. Only beaches where at least ten egress surveys were conducted are shown. Individual data points are indicated by grey diamonds. Linear regression lines fitted to the data points are shown as dashed lines. The number of egress surveys for each beach (N) and the probability of a significant slope (*p*) are given above each graph. Values of $p \leq 0.05$ indicate a significant slope. Data from all egress surveys conducted during 1989-2005.

To verify that these slopes had remained consistent over time, separate sets of graphs were generated by the three eras identified above. Results for the Early Peak (negative slope) beaches are shown in Figures 20-22. Given the reduced sample size resulting from splitting available surveys by era, our objective was primarily to verify that the sign and steepness of the slopes were *consistent*, rather than that the slopes were *significant*.

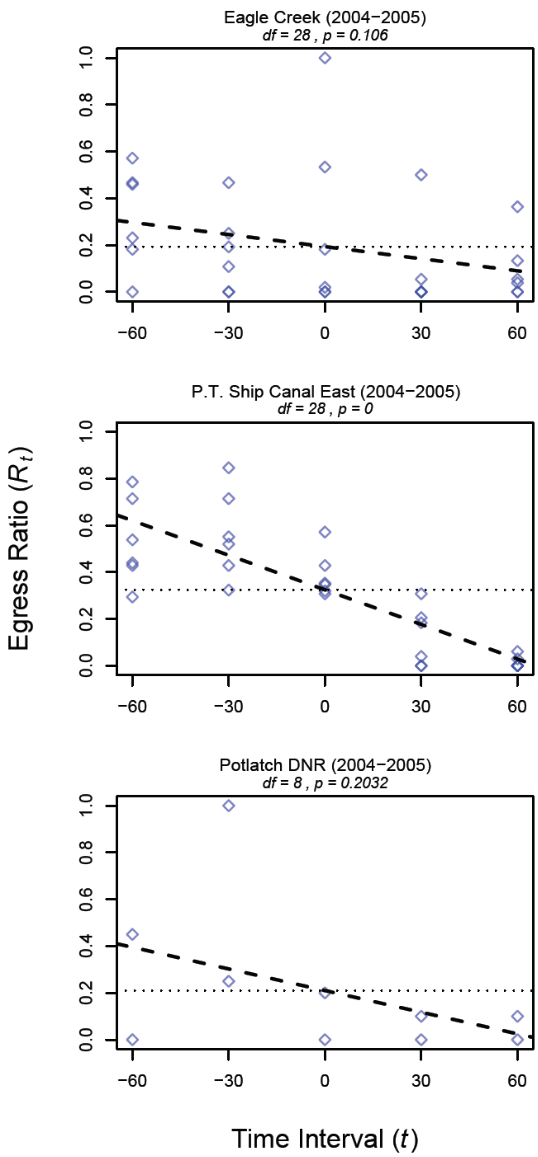

Figure 20. The distribution of all individual half-hour egress ratios (R_t) for beaches within the Early Peak group surveyed during 2004 and 2005. Individual data points are indicated by grey diamonds. Linear regression lines fitted to the data points are shown as dashed lines. The dotted line is a comparative zero-slope line drawn through the midpoint of the data. The degrees of freedom for the regression (*df*) and the probability of a significant slope (*p*) are given above each graph. Values of $p \leq 0.05$ indicate a significant slope.

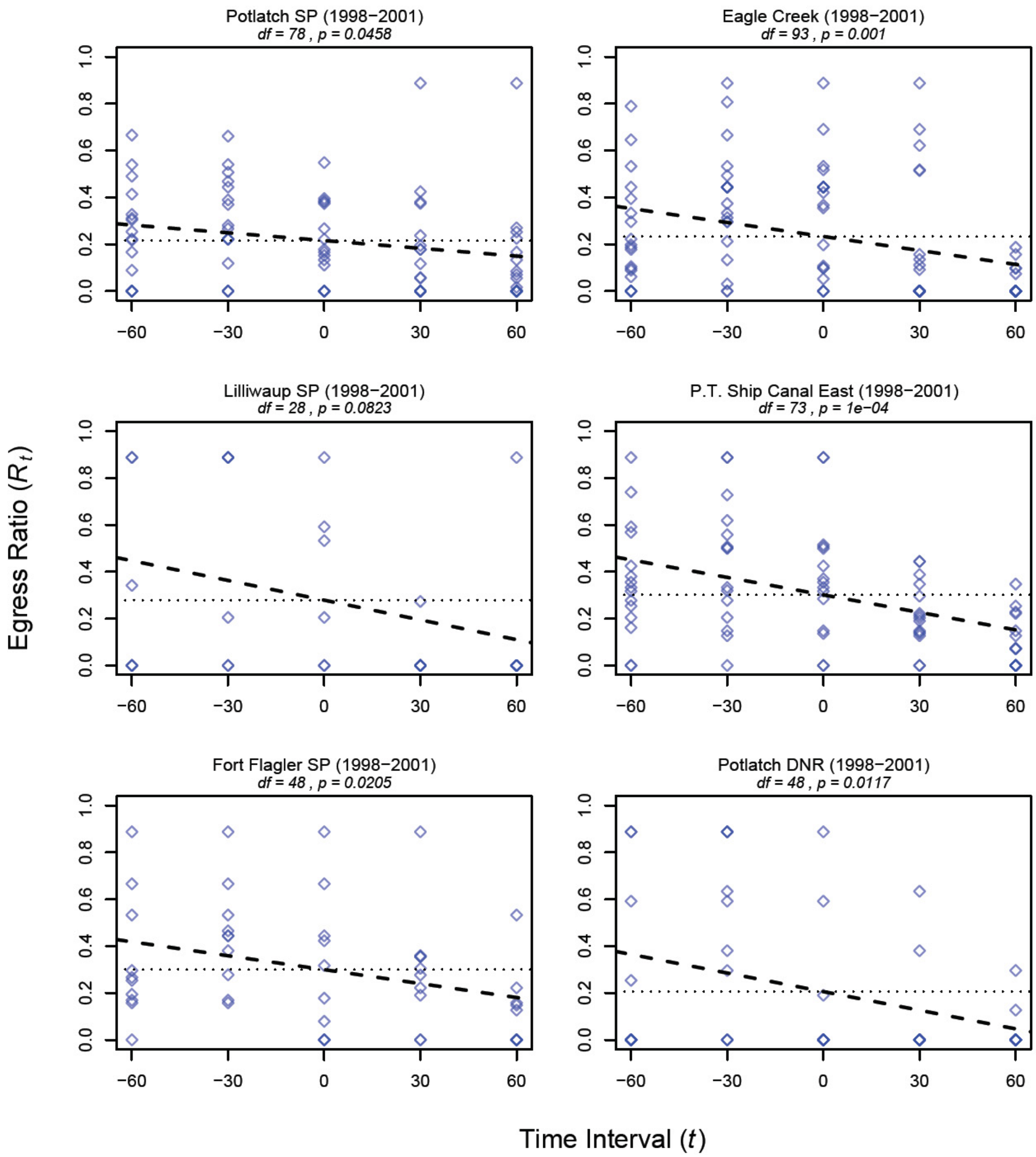

Figure 21. The distribution of all individual half-hour egress ratios (R_t) for beaches within the Early Peak group surveyed during the era 1998-2001. Individual data points are indicated by grey diamonds. Linear regression lines fitted to the data points are shown as dashed lines. The dotted line is a comparative zero-slope line drawn through the midpoint of the data. The degrees of freedom for the regression (*df*) and the probability of a significant slope (*p*) are given above each graph. Values of $p \leq 0.05$ indicate a significant slope.

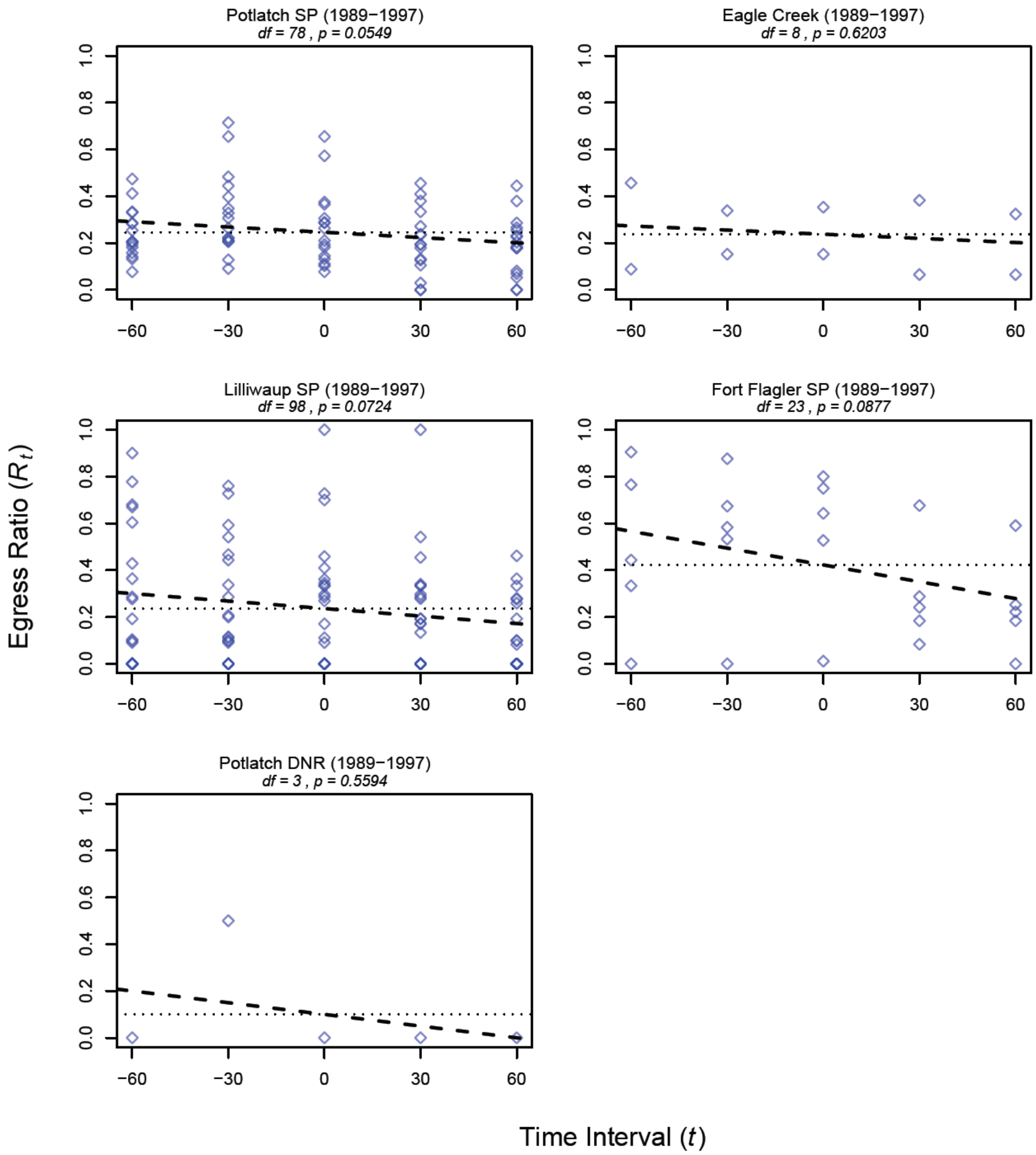

Figure 22. The distribution of all individual half-hour egress ratios (R_t) for beaches within the Early Peak group surveyed during the era 1989-1997. Individual data points are indicated by grey diamonds. Linear regression lines fitted to the data points are shown as dashed lines. The dotted line is a comparative zero-slope line drawn through the midpoint of the data. The degrees of freedom for the regression (*df*) and the probability of a significant slope (*p*) are given above each graph. Values of $p \leq 0.05$ indicate a significant slope.

During the period from 2004 to 2005, only three of the six beaches were surveyed, but none of the slopes appeared to differ in any meaningful way from the combined means, or from those of other eras. All six beaches were represented in the 1998-01 era, and all slopes were significantly negative, with the exception of Lilliwaup State Park (p = 0.0823). Only one beach was missing from the 1989 to 1997 group, but again there were no apparent differences in the sign or steepness of the slopes.

When the combined data from the six Early Peak beaches were tested versus data from all of the remaining beaches (except Twanoh State Park), significant differences were identified at every time interval except $t = 0$ (Figure 23). If flight counts on these beaches consistently occurred within 15 minutes of low tide then the non-significant result at $t = 0$ would be the only relevant value. However, histograms (Figure 24) confirmed that flight counts often occurred more than 30 minutes from the time of the low tide. These results suggested that a separate egress model should be considered for the six Early Peak beaches.

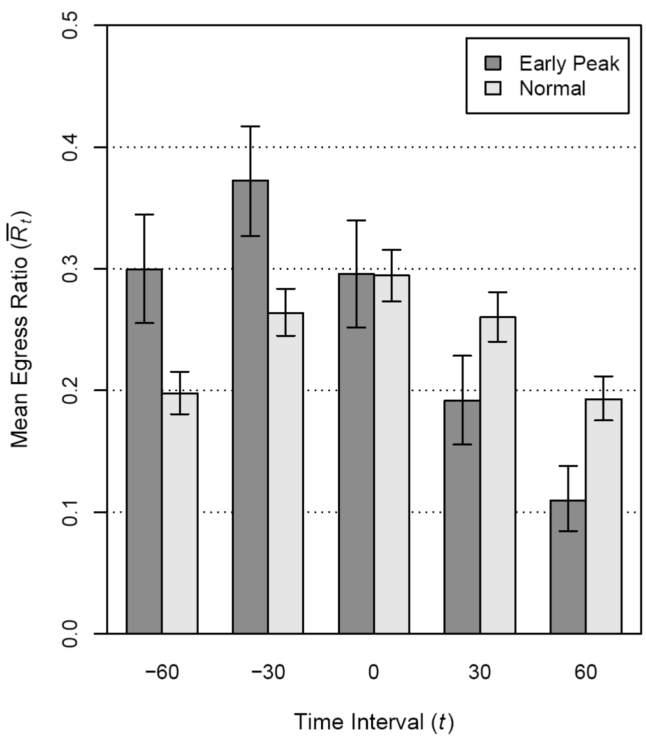

Figure 23. The mean egress ratio for each time interval ($\overline{R_t}$) on the six Early Peak beaches (dark grey bars) and all other beaches except Twanoh State Park (Normal beaches, light grey bars). The mean egress ratio ($\overline{R_t}$) for each time interval *t* is indicated by the top of each bar. Bootstrap 95% confidence intervals surrounding the means are indicated by solid black I-beams. Data from egress surveys conducted during 1989-2005.

For the one "late peak" beach (Kitsap Memorial State Park), surveys were only conducted during two of the three eras, and results were mixed (Figure 25). The slope for the 1998-2001 era was significant, but there were insufficient data to verify results over time. There was only one survey conducted prior to 1998, and the egress curve for this survey was essentially symmetric, with little indication of any slope. Given our inability to compare data over time, and the high variability evident in the 1998-2001 data, we concluded that new surveys would be required before attempting to assign a unique egress model to this beach.

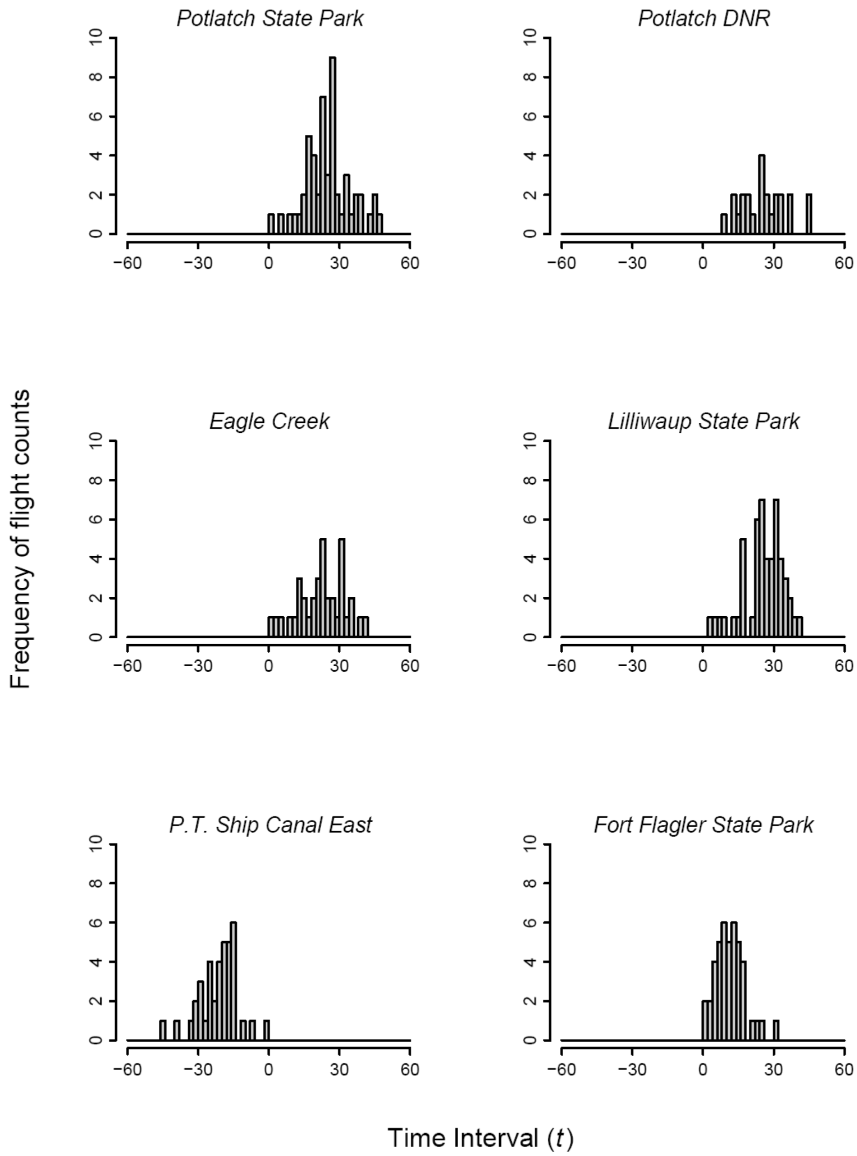

Figure 24. The frequency distribution of instantaneous aerial counts of sport harvesters on the six Early Peak beaches relative to local low tide. Data, in one-minute intervals, were obtained from aerial surveys in 2004-2005.

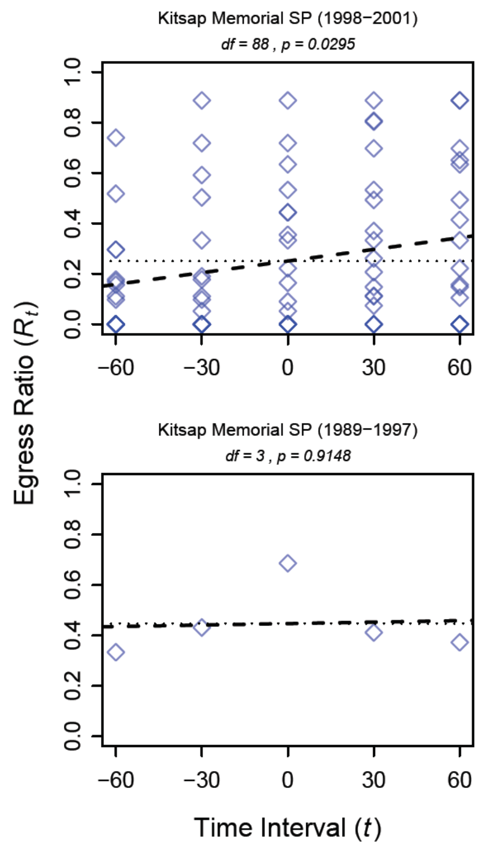

Figure 25. The distribution of all individual half-hour egress ratios (R_t) for Kitsap Memorial State Park from surveys in 1998-2001 (top) and 1989-1997 (bottom). Individual data points are indicated by grey diamonds. Linear regression lines fitted to the data points are shown as dashed lines. The dotted line is a comparative zero-slope line drawn through the midpoint of the data. The degrees of freedom for the regression (*df*) and the probability of a significant slope (*p*) are given above each graph. Values of $p \leq 0.05$ indicate a significant slope.

2.5) Effort proportions at low tide

The graphs in Figure 14 suggested that the mean and median egress ratios recorded exactly at low tide ($t = 0$) may have been higher on certain beaches (such as Dosewallips State Park and Duckabush than on other beaches. To objectively identify beaches with higher than normal effort peaks, multiple comparisons of mean proportions at low tide ($t = 0$) were conducted using the Dunnet procedure (Figure 26). The R function *simint* was used to generate one-sided 95% CIs. The baseline for comparison was the mean proportion at low tide for Twanoh State Park. The Twanoh State Park values were used as a baseline because they were based on a large number of surveys ($n = 64$), and the egress curve peaks were significantly lower than the combined means for all other beaches (Figure 17).

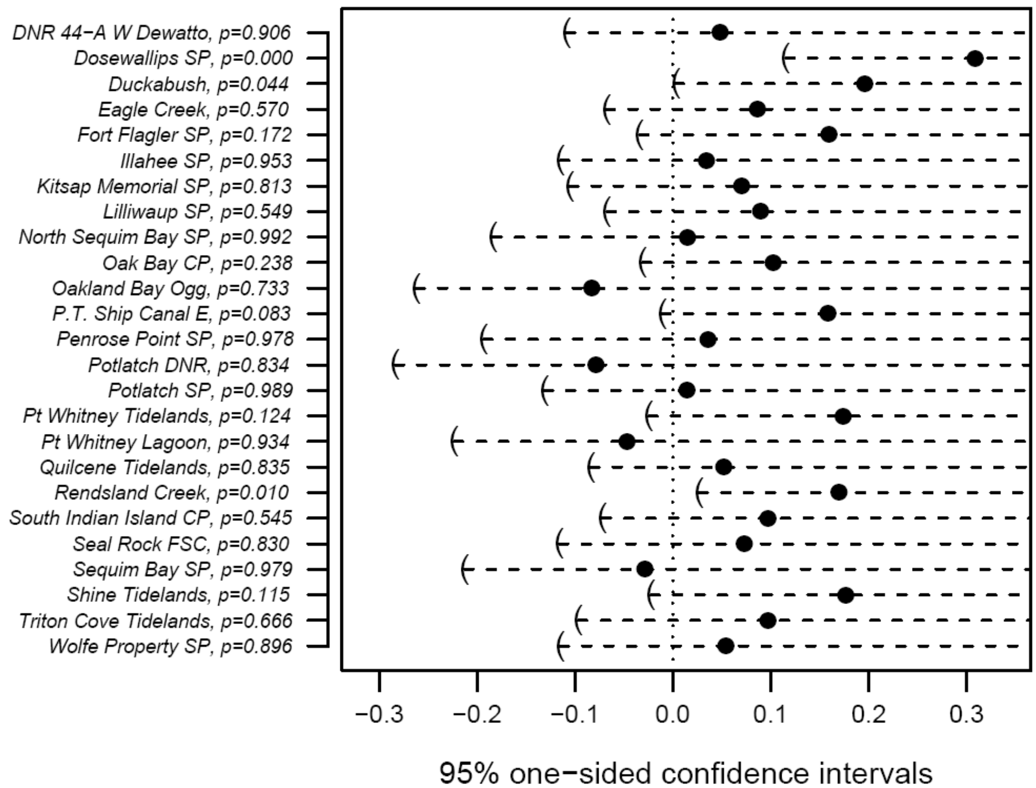

Figure 26. Multiple comparisons of the mean egress ratio at local low tide $(\overline{R}_0)$ for 25 beaches compared to $(\overline{R}_0)$ at Twanoh State Park. Only beaches where at least ten egress surveys were conducted are shown. Multiple comparisons were made using the Dunnet procedure. Mean values are shown as black dots. The one-sided 95% confidence intervals are shown as dotted lines. The probability that $(\overline{R}_0)$ for a beach differs significantly from the $(\overline{R}_0)$ for Twanoh State Park (*p*) is given beside each beach name. Values of $p \leq 0.05$ indicate a significant difference.

Results shown in Figure 26 suggested that only three beaches had unusually high effort peaks at low tide: Dosewallips State Park, Duckabush, and Rendsland Creek. When the combined data from this subset of High Peak beaches were tested versus Normal beaches, significant differences were identified at all but the + 60 and – 60 minute intervals (Figure 27). The Normal group in this test included all beaches except Twanoh State Park and the six beaches identified in the previous section as having “early peaks.” Histograms showing the timing of flight counts for the High Peak group (Figure 28) confirmed that aerial surveys occurred primarily within 30 minutes of low tide. Results therefore suggested that the three beaches in the High Peak group should be considered as candidates for a separate egress model.

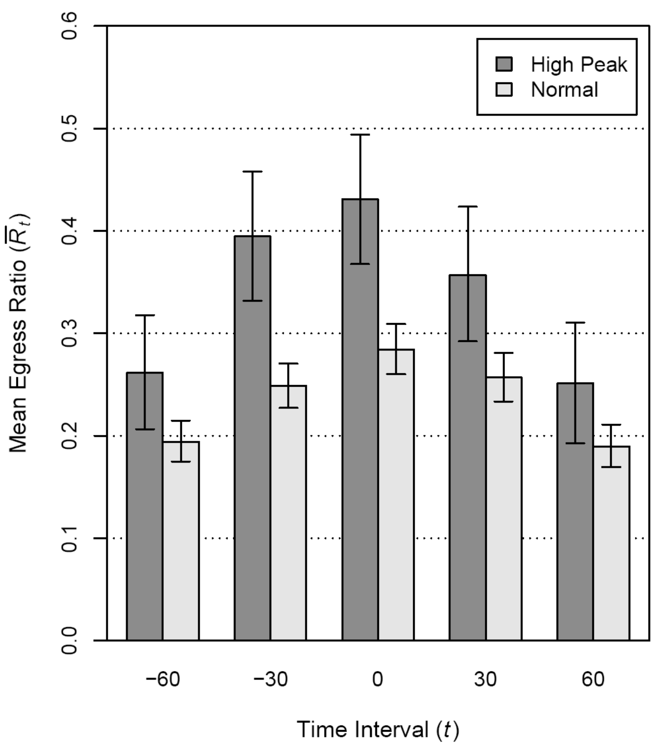

Figure 27. The mean egress ratio for each time interval ($\overline{R_t}$) on the three High Peak beaches (dark grey bars) and all Normal beaches (all beaches except Twanoh State Park and the six Early Peak beaches, light grey bars). The mean egress ratio ($\overline{R_t}$) for each time interval t is indicated by the top of each bar. Bootstrap 95% confidence intervals surrounding the means are indicated by solid black I-beams. Data from egress surveys conducted during 1989-2005.

2.6) Final tests

A final set of tests was necessitated for three reasons. First, as candidate strata were identified during the previous analysis, the Normal group of beaches was redefined to exclude beaches in the newly identified strata groupings. This may have altered the outcome of earlier tests. Second, the beach-specific candidate strata (Twanoh State Park, Early Peak and High Peak beaches) needed to be tested to see if the existing three tide-day strata could also be applied to them. Third, any ambiguity in results needed to be resolved. For this final set of tests the egress data were separated into the three beach-specific groups outlined above (Early Peak, High Peak, and Twanoh State Park), and a Normal group that consisted of all remaining beaches.

When the Normal group of beaches was separated by ELOW and non-ELOW strata, comparisons using the bootstrap CI method (Figure 29) confirmed that significant differences (in terms of non-overlapping CIs) existed at every time interval except at -30 minutes, where the overlap was small (0.00051). Given the clear separation at all other intervals and the small overlap at –30 minutes, we determined that there was sufficient evidence to further stratify the Normal group of beaches by ELOW and non-ELOW strata.

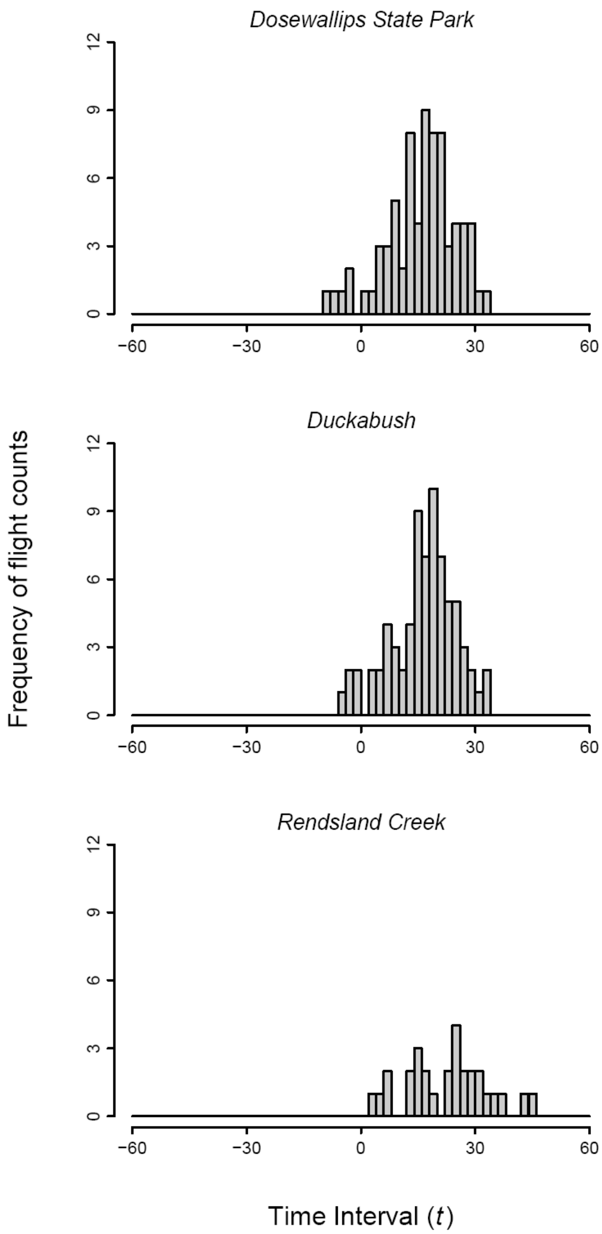

Figure 28. The frequency distribution of instantaneous aerial counts of sport harvesters on the three High Peak beaches relative to local low tide. Data, in one-minute intervals, were obtained from aerial surveys in 2004-2005.

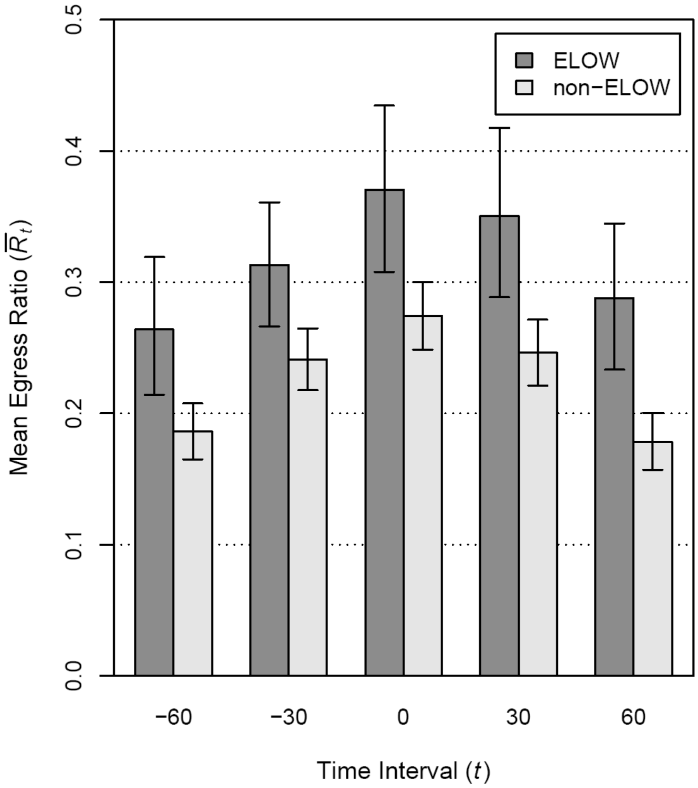

Figure 29. The mean egress ratio for each half-hour time interval ($\overline{R_t}$) on Normal beaches, comparing the ELOW stratum (dark grey bars) and the non-ELOW strata (light grey bars). Normal beaches are all beaches except the six Early Peak beaches, the three High Peak beaches, and Twanoh State Park. The mean egress ratio ($\overline{R_t}$) for each time interval is indicated by the top of each bar. Bootstrap 95% confidence intervals surrounding the means are indicated by solid black I-beams. Data from egress surveys conducted during 1989-2005.

Comparisons of Twanoh State Park versus the Normal group produced inconclusive results (Figure 30, panel A). With data from the Early Peak and High Peak beaches removed, CIs overlapped at every time interval except +30 minutes. From a practical standpoint, however, 90.3 % of all flight counts at Twanoh State Park in 2004 and 2005 were made within 15 minutes of the +30 minute time interval that tested significant (Figure 17, panel D). To resolve this ambiguity, we conducted a set of ANCOVA tests described below. Comparisons of tide-day strata at Twanoh State Park, on the other hand, were more clear-cut (Figure 30, panel B). CIs for the mean egress ratios of the ELOW and non-ELOW strata overlapped at every time interval. Thus, there was insufficient evidence to support establishing separate ELOW and non-ELOW strata for this beach.

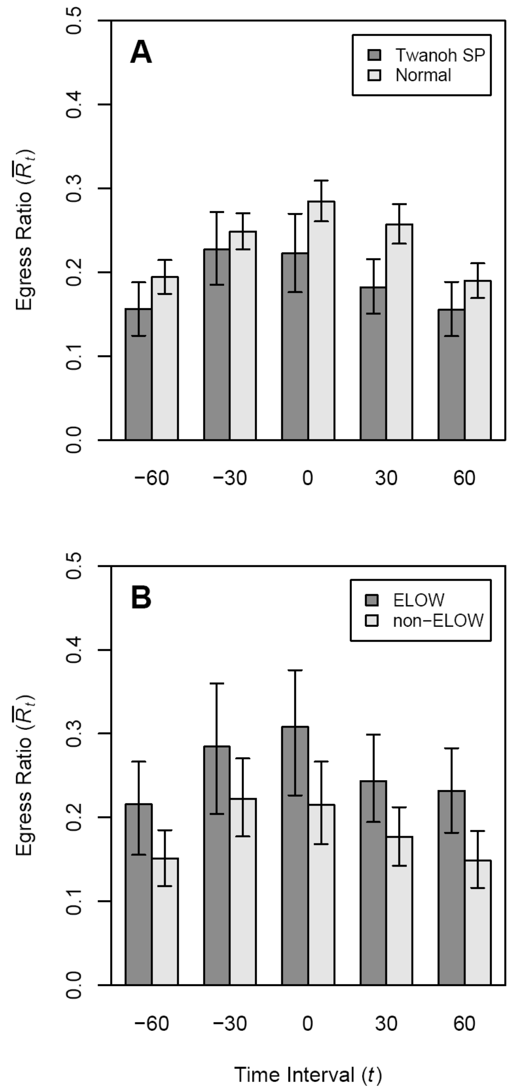

Figure 30. A comparison of the mean egress ratio for each half-hour time interval ($\overline{R_t}$) at Twanoh State Park and Normal beaches (panel A), and the ELOW and non-ELOW strata at Twanoh State Park (panel B). The mean egress ratio ($\overline{R_t}$) for each time interval is indicated by the top of each bar. Bootstrap 95% confidence intervals surrounding the means are indicated by solid black I-beams. Data from egress surveys conducted during 1989-2005.

To resolve the question of whether a separate beach-specific egress model should be used to expand harvester counts at Twanoh State Park, a third set of tests were conducted using non-parametric ANCOVA of the egress curves. The R function *sm.ancova* (Bowman and Azzalini 1997) was used for the analysis. Smoothed regression lines for Twanoh and the Normal group of beaches were fitted to data over the five time intervals. The resulting lines were then tested for equality. The smoothing parameter was set to $h = 5$. This was a compromise between the $h = 3.3$ and $h = 8.3$ values produced by the *h.select* function in the *sm* library using the default, and cross-validation methods, respectively. Setting $h = 5$ also had the advantage of producing a minimally smoothed line with nodes at each time interval. Results (Figure 31, panel A) indicated that there was a significant difference between the two lines ($p = 0.011$), and that the area of significant separation extended along the time interval scale from about 0 to +50 minutes. The shaded area between the egress curves indicated where results were not statistically significant. The span from 0 to + 50 minutes encompassed 98.4% of all flight counts at Twanoh State Park in 2004 and 2005. Results provided sufficient evidence to conclude that a separate egress model should be used to expand harvester counts at Twanoh State Park.

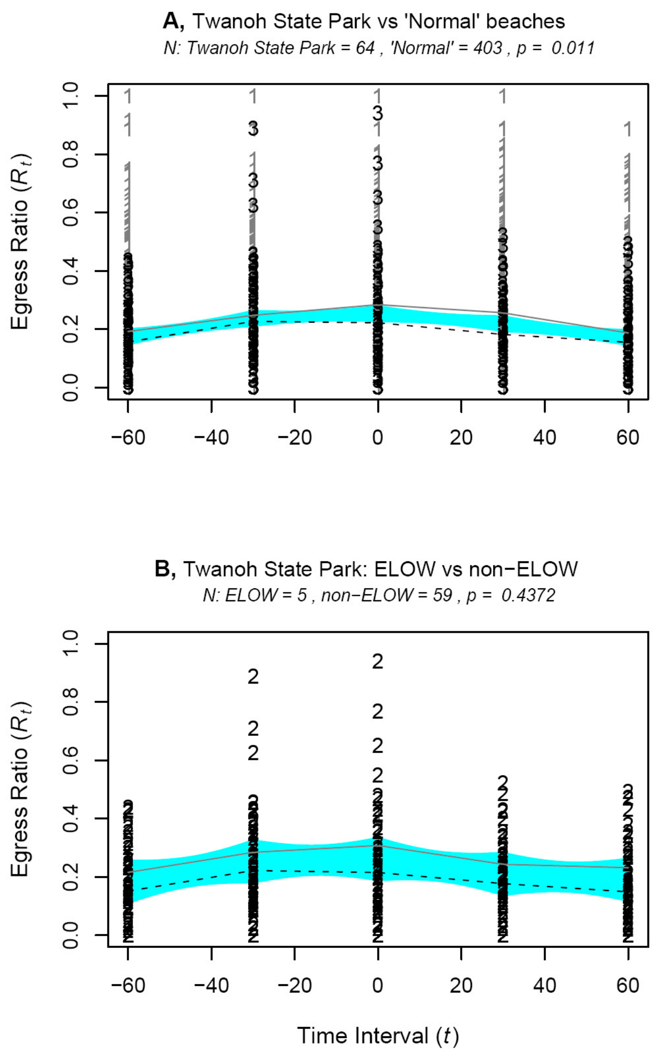

Figure 31. Results of a non-parametric ANCOVA for the egress curve at Twanoh State Park. In panel A, the black dashed line is the egress curve for Twanoh State Park, and the solid gray line is the egress curve for all Normal beaches. In panel B, the black dashed line is an egress curve for the ELOW stratum at Twanoh State Park , and the solid gray line is an egress curve for the non-ELOW strata at Twanoh State Park. In both panels, the shaded areas between the two curves indicate where there was no statistically significant difference. Values of $p \leq 0.05$ indicate a significant difference between the two egress curves. In both panels, data values for each group are indicated by numeric symbols and are shown in the same colors as the respective lines.

The ANCOVA procedure was also used to test if separate ELOW and non-ELOW strata should be applied to the Twanoh State Park data. Results (Figure 31, panel B) confirmed that this hypothesis should be rejected (p = 0.4372). The low sample size in the ELOW category (N = 5), however, suggested that additional ELOW surveys should conducted at Twanoh State Park, and that potential strata should be reassessed as new data becomes available.

Comparisons of the Early Peak versus Normal group of beaches (Figure 32, panel A) reconfirmed that a separate egress model was warranted for the Early Peak group. There was insufficient evidence, however, to further stratify this group of beaches by ELOW and non-ELOW strata (Figure 32, panel B).

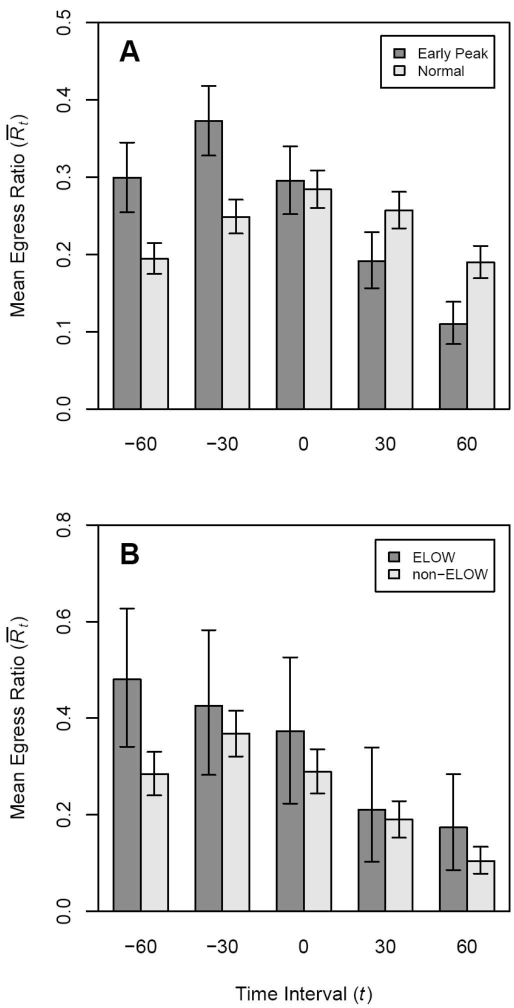

Figure 32. The mean egress ratio for each half-hour time interval ($\overline{R_t}$) at the six Early Peak beaches compared with Normal beaches (panel A), and the ELOW and non-ELOW strata at Early Peak beaches (panel B). Early Peak beaches are: Potlatch State Park, Potlatch DNR, Lilliwaup State Park, Eagle Creek, Fort Flagler State Park, and P.T. Ship Canal East. The mean egress ratio ($\overline{R_t}$) for each time interval is indicated by the top of each bar. Bootstrap 95% confidence intervals surrounding the means are indicated by solid black I-beams. Data from egress surveys conducted during 1989-2005.

Results were similar for the High Peak group when CIs were compared against Normal beaches (Figure 33, panel A). Separation between CIs was evident at each time interval from -30 to +30 minutes, and coincided with the time-span where 93.2% of all flight counts in the High Peak group occurred in 2004 and 2005. This reconfirmed earlier results that a separate egress model for this group was appropriate. There was no indication, however, that ELOW and non-ELOW strata should also be applied to this group (Figure 33, panel B).

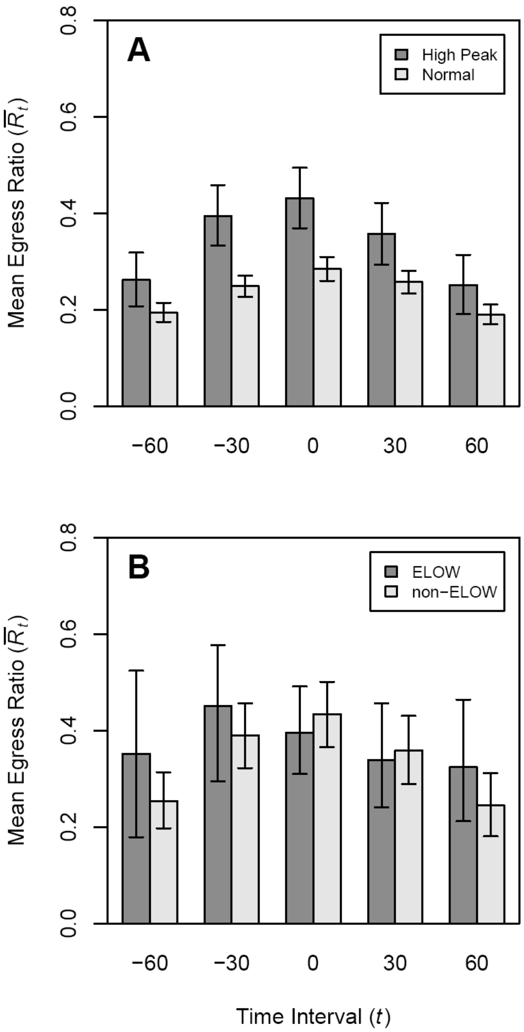

Figure 33. The mean egress ratio for each half-hour time interval ($\overline{R_t}$) at the three High Peak beaches compared with Normal beaches (panel A), and the ELOW and non-ELOW strata at High Peak beaches (panel B). High Peak beaches are: Dosewallips State Park, Duckabush, and Rendsland Creek. The mean egress ratio ($\overline{R_t}$) for each time interval is indicated by the top of each bar. Bootstrap 95% confidence intervals surrounding the means are indicated by solid black I-beams. Data from egress surveys conducted during 1989-2005.

3) Oakland Bay egress data

As outlined in the *Timing of Flight Counts* analysis, the Oakland Bay egress data presented a unique set of questions. Because the "true" local low at Oakland Bay typically occurs ~ 45 minutes after the published low at Shelton, flight counts in 2004-05 occurred on average 107 minutes prior to the "true" low tide. This raised the possibility that harvester behavior at Oakland Bay might differ enough to warrant a separate egress model, or that the flight route would need to be adjusted to count harvesters closer to the actual low tide. To assess this graphically, the entire set of egress data over the full six hours of available surveys were plotted (Figure 34). The mean egress ratio $\overline{R}_t$ (black dashed line) indicated a unique bimodal structure to the egress data, but despite the 45-minute offset between the "true" local low and published values at Shelton, the proportion of effort remained symmetric about the Shelton low ($t = 0$). The median values of R_t (dotted line, Figure 34) peaked at –60 minutes, which is when most flight counts occurred in 2004-05 (Figure 35).

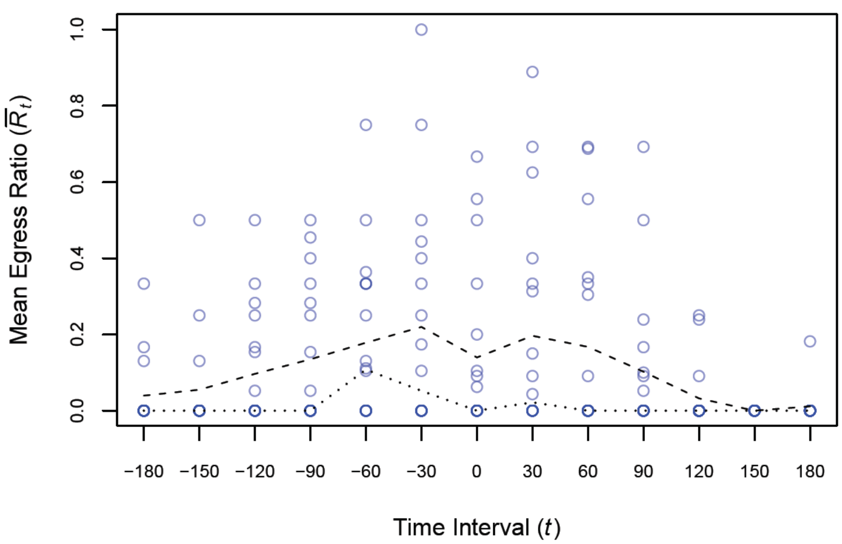

Figure 34. Egress curves at Oakland Bay Ogg. The dashed line denotes mean values ($\overline{R}_t$) and the dotted line indicates median values. Light grey circles represent individual data points; darker circles indicate a higher density of overlapping data points.

Given the high number of zero values in the Oakland Bay egress data, the median was clearly not the most appropriate measure of centrality to use for expanding harvester counts, but it did indicate the time interval where the probability of seeing harvest activity was highest. For example, using the available egress data, the probability of seeing more than zero harvesters during an aerial survey was $p = 0.55$ at the -60 minute interval, and $p = 0.44$ at the 0 minute interval. This suggests that the aerial survey route as presently structured provided a higher estimate of total effort than would be the case if counts occurred exactly at the Shelton low tide, where both the mean proportion of harvest effort and probability of seeing harvest activity were lower. These results will need to be reassessed, however, once additional egress data becomes available.

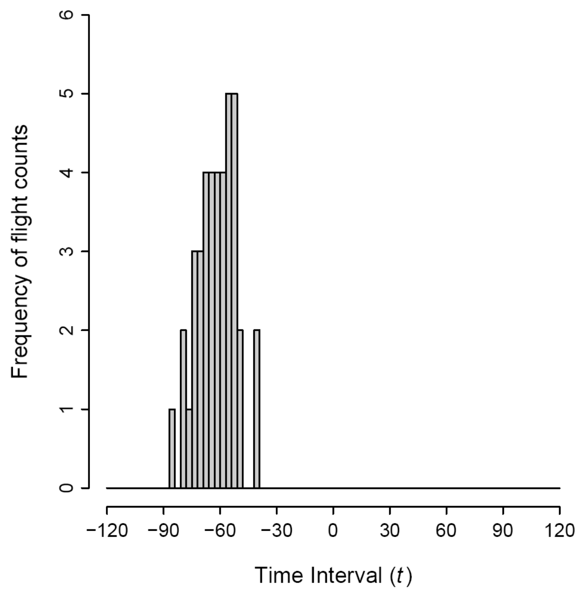

Figure 35. The frequency distribution of instantaneous aerial counts of sport harvesters at Oakland Bay Ogg relative to Shelton low tide. Data, in one-minute intervals, were obtained from aerial surveys in 2004-2005.

Additional data will be necessary to determine if the bimodal structure of the egress data indicated in Figure 34 is robust, and not the result of just a few anomalous values. If so, then a separate egress model for Oakland Bay beaches may be appropriate.

Comparisons of Oakland Bay egress ratios versus those on the Normal set of beaches (Figure 36, panel A) indicated that the only significant difference occurred at low tide ($t = 0$). No significant differences were detected at time intervals -60 or –30 minutes, where the great majority of counts occurred in the 2004-05 flight data. In fact, 90% of all flight counts occurred within the range of -40 to -75 minutes relative to the Shelton low tide (Figure 35). The maximum and minimum values were -40 and -86 minutes respectively.

Comparisons to determine if tide-day strata should be applied to the Oakland Bay data (Figure 36, panel B) were inconclusive due in part to low sample size. There were only two ELOW surveys compared to 16 non-ELOW surveys. One significant difference (in terms of non-overlapping CIs) was detected at the +60 minute interval, but more surveys will be needed to verify this result. It is worth noting, however, that during both of the ELOW surveys the maximum count of harvesters within the 2-hr block centered on low tide occurred a full hour after the Shelton low tide.

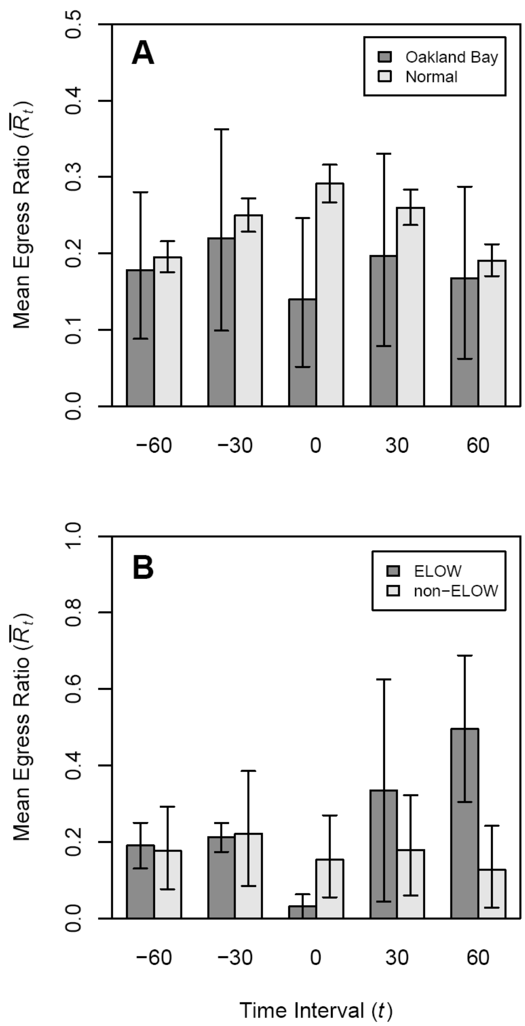

Figure 36. The mean egress ratio for each half-hour time interval ($\overline{R_t}$) at Oakland Bay Ogg compared with Normal beaches (panel A), and the ELOW and non-ELOW strata at Oakland Bay Ogg (panel B). The mean egress ratio ($\overline{R_t}$) for each time interval is indicated by the top of each bar. Bootstrap 95% confidence intervals surrounding the means are indicated by solid black I-beams. Data from egress surveys conducted during 1989-2005.

4) Expansion factors and variance estimates

Two alternate methods for deriving expansion factors and variance for those factors at points along the egress curve were considered below. The first method consisted of treating the egress curve as a step-function with expansion factors and variance estimates changing only at each 30-minute time interval. The second method used an interpolating cubic spline function to generate "smoothed" estimates at one-minute intervals along the egress curves.

Aerial and ground-based harvester counts are recorded to the nearest minute. Using the step-function method, the requisite values for expansion and variance would simply be those that fell closest to the count within a 15-minute range. For example, if a count was recorded 17 minutes after the local low tide, the closest interval would be + 30 minutes; if the count occurred at 11 minutes after the low tide, then the closest interval would be at time 0. Point values derived at + 30 minutes and 0 minutes, respectively could then be used for expansion and variance.

The primary disadvantage of this method is that it may introduce systematic bias into counts recorded at specific beaches. The timing of flight counts is random to the extent that factors such as winds or ground delays can alter when a flyover occurs. At Sequim Bay, where the flight route starts, the variability in count times is fairly small, but as the survey progresses, wind speed and direction may play an increasingly important role, often resulting in greater variability. For example, flight data from 2004 and 2005 shows that the spread between maximum and minimum times when flyover counts were made at Sequim Bay was 28 minutes. A majority of those counts (74%) fell between zero and ten minutes after the low tide. By contrast, at Oakland Bay in southern Puget Sound, the spread between minimum and maximum times when flyover counts were made was 46 minutes. Greater variability in this context is favorable, because there is less chance that a majority of counts would consistently cluster along a portion of the egress curve just to one side of the dividing line between 30-minute increments.

Curves for the five egress models (Figure 37, panel A) illustrated the potential magnitude of the problem when using a step-function. The point values for mean daily proportion of all-day effort ($\overline{R}_t$) were plotted along with interpolating cubic splines. Using the Early Peak model as an extreme example, it was apparent that the difference between a set of counts that clustered near a break in the proposed step-function within a range of 30 minutes on either side of low tide could be assigned values significantly different from those assigned if the counts were to cluster a few minutes to the other side of the step-function break. This is a realistic scenario given that counts at two of the beaches in the Early Peak group (Fort Flagler State Park and P.T. Ship Canal East) occur early in the survey. These are also two of our most heavily used beaches. .

To avoid potential bias, the second option was to assume that the underlying "true" egress models were smooth curves, and interpolate values for the mean egress ratio and its variance using the cubic spline function shown in Figure 37. Here the point values at each 30-minute interval were calculated using the R function *smean.sd* which assumes a normal distribution, as opposed to the bootstrap method used earlier in the analysis. A comparison of methods, summarized in Table 9, confirmed that despite the non-normal appearance of the data (Figure 10), the normal approximation yields essentially the same values as the bootstrap method, even when sample size is relatively small (maximum N = 43; Table 10). In each of the cases tested, differences in results were restricted to the third decimal. The R function *spline* was used to interpolate expansion and variance values at one-minute increments along each egress model.

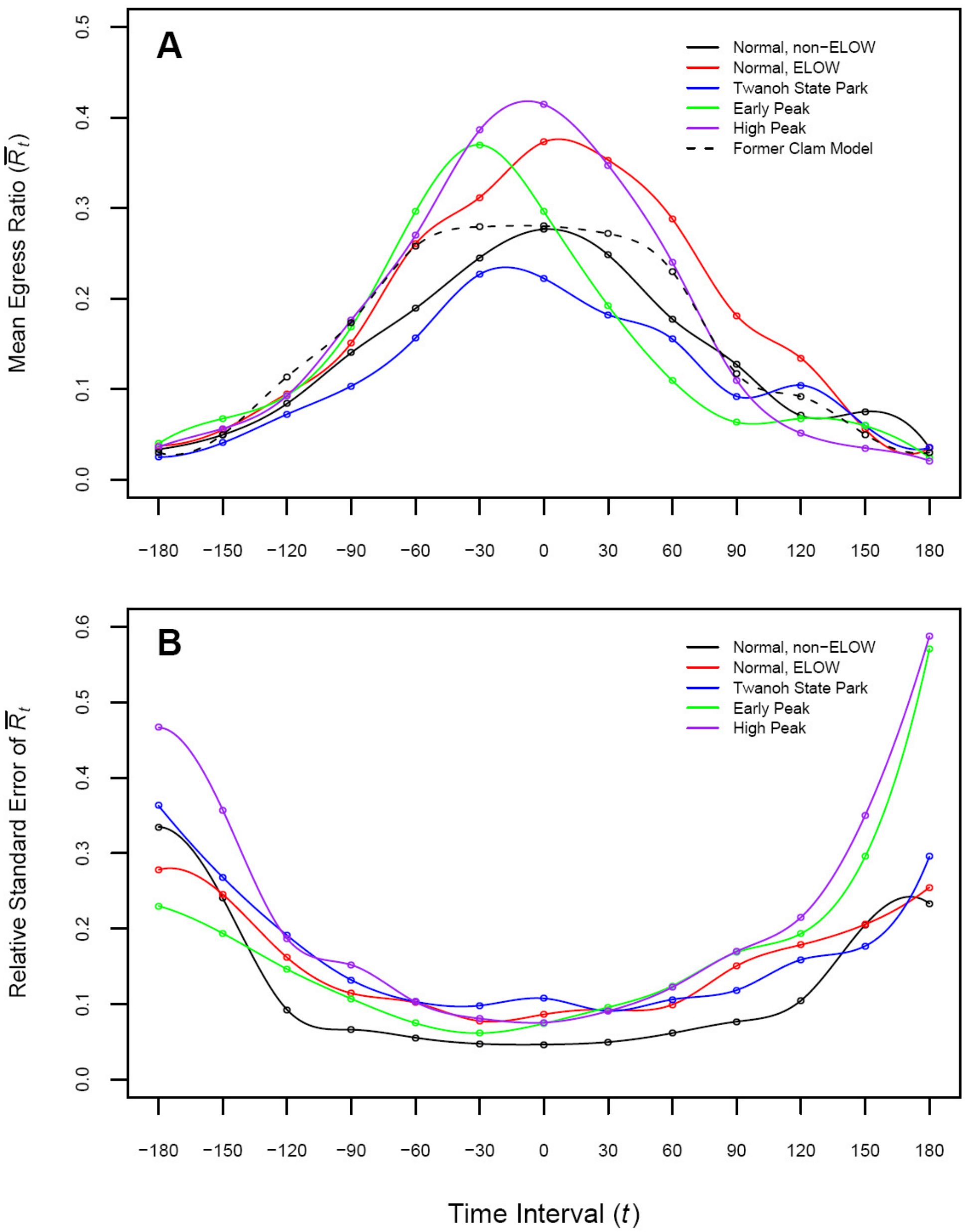

Figure 37. The five egress models (panel A) and Relative Standard Error (RSE) for points along each model curve (panel B). Also shown for comparative purposes in panel A is the egress model formerly used for "clam beaches" prior to 2007 (dotted line). Values of RSE are not available for the former "clam beach" egress model. All values between 30-minute time intervals were interpolated with a cubic spline function. High Peak beaches are: Dosewallips State Park, Duckabush, and Rendsland Creek. Early Peak beaches are: Potlatch State Park, Potlatch DNR, Lilliwaup State Park, Eagle Creek, Fort Flagler State Park, and P.T. Ship Canal East.

Table 9. A comparison between normal parametric and bootstrap non-parametric 95% confidence intervals (CI) around the mean egress ratio ($\overline{R_t}$) for the Normal, ELOW egress model. Bootstrap results were derived using the R function smean.cl.boot.

Time Interval	*Bootstrap (n = 10,000)*			*Parametric*		*Difference*	
	Mean	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**	**Upper**
-180	0.0376	0.0188	0.0590	0.0163	0.0590	0.003	0.000
-150	0.0551	0.0306	0.0828	0.0275	0.0828	0.003	0.000
-120	0.0951	0.0659	0.1258	0.0640	0.1261	0.002	0.000
-90	0.1512	0.1180	0.1852	0.1162	0.1861	0.002	-0.001
-60	0.2604	0.2125	0.3149	0.2069	0.3140	0.006	0.001
-30	0.3119	0.2633	0.3585	0.2630	0.3607	0.000	-0.002
0	0.3731	0.3097	0.4361	0.3081	0.4382	0.002	-0.002
30	0.3531	0.2915	0.4187	0.2871	0.4192	0.004	0.000
60	0.2880	0.2338	0.3447	0.2302	0.3458	0.004	-0.001
90	0.1813	0.1331	0.2374	0.1261	0.2364	0.007	0.001
120	0.1344	0.0937	0.1855	0.0860	0.1829	0.008	0.003
150	0.0557	0.0354	0.0791	0.0323	0.0792	0.003	0.000
180	0.0352	0.0193	0.0536	0.0169	0.0535	0.002	0.000

Panel B of Figure 37 shows the relative standard error (RSE) of the egress ratio, at 30-minute intervals, for each of the five egress models. Over the critical interval where all flight counts, other than those at Oakland Bay and Silverdale Shoal, occur (-60 to +60 minutes, Figure 8) the RSE was less than 0.125 for all models (Table 10). RSEs for the Normal group of beaches were considerably smaller over the same interval when restricted to non-ELOW strata. Values were less than 0.065 in each case. The Normal group consisted of 29 out of the 39 beaches from which data were available.

It is also worth noting that over the same 2-hr interval, egress curves (Figure 37, panel A) were relatively smooth for all but the Normal ELOW (N = 43), and Twanoh (N = 64) groups. These were the groups with the smallest sample sizes over the interval (Table 10). Given higher sample sizes in these groups it would be reasonable to assume that the respective egress curves will also begin to approximate the presumed underlying smoother "true" functions.

Tables 11-15 provide values of the mean egress ratio ($\overline{R_t}$) and its variance for all five egress models at one-minute time intervals between –60 and +60 minutes, based on the interpolating cubic spline function.

In Part I of this report, we provide step-by-step equations currently used in estimating daily (all-day) sport effort and its variance, as well as season-long sport effort and its variance.

Table 10. Descriptive statistics for the five current egress models. Values shown for each half-hour time-interval include the mean egress ratio ($\overline{R_t}$), standard deviation of the data (SD), standard error of the mean (SE), relative standard error (RSE), and sample size (N).

	Normal, non-ELOW					*Normal, ELOW*				
Time Interval	R_t	**SD**	**SE**	**RSE**	**N**	R_t	**SD**	**SE**	**RSE**	**N**
-180	0.034	0.125	0.0113	0.335	123	0.038	0.058	0.0105	0.278	31
-150	0.050	0.132	0.0119	0.240	123	0.055	0.075	0.0135	0.246	31
-120	0.084	0.152	0.0078	0.093	380	0.095	0.101	0.0154	0.162	43
-90	0.140	0.181	0.0093	0.066	380	0.151	0.113	0.0173	0.114	43
-60	0.189	0.205	0.0105	0.056	379	0.260	0.174	0.0265	0.102	43
-30	0.245	0.226	0.0116	0.047	377	0.312	0.159	0.0242	0.078	43
0	0.277	0.250	0.0129	0.046	377	0.373	0.211	0.0322	0.086	43
30	0.248	0.240	0.0124	0.050	378	0.353	0.215	0.0327	0.093	43
60	0.177	0.211	0.0109	0.062	373	0.288	0.185	0.0286	0.099	42
90	0.127	0.190	0.0098	0.077	378	0.181	0.179	0.0273	0.151	43
120	0.071	0.144	0.0074	0.105	379	0.134	0.157	0.0240	0.179	43
150	0.075	0.171	0.0154	0.205	123	0.056	0.064	0.0115	0.206	31
180	0.035	0.091	0.0082	0.233	123	0.035	0.050	0.0090	0.255	31

	Early Peak					*High Peak*				
Time Interval	R_t	**SD**	**SE**	**RSE**	**N**	R_t	**SD**	**SE**	**RSE**	**N**
-180	0.040	0.068	0.0092	0.230	55	0.036	0.096	0.0169	0.467	32
-150	0.068	0.097	0.0131	0.194	55	0.056	0.114	0.0202	0.357	32
-120	0.093	0.160	0.0136	0.146	138	0.093	0.145	0.0174	0.187	70
-90	0.169	0.213	0.0181	0.107	139	0.176	0.224	0.0268	0.152	70
-60	0.296	0.261	0.0221	0.075	139	0.270	0.229	0.0278	0.103	68
-30	0.370	0.267	0.0228	0.062	138	0.386	0.258	0.0312	0.081	68
0	0.296	0.260	0.0220	0.074	139	0.415	0.260	0.0313	0.076	69
30	0.192	0.216	0.0184	0.096	137	0.347	0.264	0.0315	0.091	70
60	0.109	0.160	0.0136	0.124	139	0.240	0.244	0.0294	0.123	69
90	0.063	0.126	0.0107	0.169	138	0.110	0.156	0.0187	0.170	70
120	0.068	0.154	0.0131	0.193	139	0.051	0.093	0.0111	0.215	70
150	0.060	0.131	0.0176	0.296	55	0.035	0.069	0.0123	0.350	32
180	0.025	0.104	0.0140	0.571	55	0.021	0.069	0.0123	0.588	32

	Twanoh State Park				
Time Interval	R_t	**SD**	**SE**	**RSE**	**N**
-180	0.025	0.063	0.009	0.363	48
-150	0.041	0.076	0.011	0.268	48
-120	0.072	0.111	0.014	0.191	64
-90	0.103	0.109	0.014	0.132	64
-60	0.156	0.129	0.016	0.103	64
-30	0.227	0.178	0.022	0.098	64
0	0.222	0.191	0.024	0.108	64
30	0.182	0.133	0.017	0.091	64
60	0.155	0.132	0.016	0.106	64
90	0.092	0.087	0.011	0.119	64
120	0.104	0.133	0.017	0.159	64
150	0.060	0.073	0.011	0.177	48
180	0.035	0.072	0.010	0.296	48

Table 11. Point values of the mean egress ratio ($\overline{R_t}$) at one-minute intervals for the Normal, non-ELOW egress model. Values for the mean, standard deviation of the data (SD), standard error of the mean (SE), relative standard error (RSE) for all time intervals between even half-hours were interpolated using a cubic spline function.

60 minutes prior to low tide

Time Interval	$\overline{R_t}$	SD	SE	RSE
-60	0.189	0.205	0.0105	0.056
-59	0.191	0.205	0.0105	0.055
-58	0.193	0.206	0.0106	0.055
-57	0.195	0.207	0.0106	0.054
-56	0.196	0.207	0.0106	0.054
-55	0.198	0.208	0.0107	0.054
-54	0.200	0.209	0.0107	0.053
-53	0.202	0.209	0.0107	0.053
-52	0.204	0.210	0.0108	0.053
-51	0.206	0.210	0.0108	0.052
-50	0.208	0.211	0.0108	0.052
-49	0.210	0.212	0.0109	0.052
-48	0.212	0.212	0.0109	0.051
-47	0.213	0.213	0.0109	0.051
-46	0.215	0.214	0.0110	0.051
-45	0.217	0.215	0.0110	0.050
-44	0.219	0.215	0.0110	0.050
-43	0.221	0.216	0.0111	0.050
-42	0.223	0.217	0.0111	0.050
-41	0.225	0.217	0.0112	0.049
-40	0.227	0.218	0.0112	0.049
-39	0.229	0.219	0.0112	0.049
-38	0.231	0.220	0.0113	0.049
-37	0.233	0.220	0.0113	0.049
-36	0.235	0.221	0.0114	0.048
-35	0.236	0.222	0.0114	0.048
-34	0.238	0.223	0.0115	0.048
-33	0.240	0.223	0.0115	0.048
-32	0.242	0.224	0.0115	0.048
-31	0.244	0.225	0.0116	0.048
-30	0.245	0.226	0.0116	0.047
-29	0.247	0.227	0.0117	0.047
-28	0.249	0.228	0.0117	0.047
-27	0.250	0.229	0.0118	0.047
-26	0.252	0.230	0.0118	0.047
-25	0.253	0.230	0.0119	0.047
-24	0.255	0.231	0.0119	0.047
-23	0.256	0.232	0.0120	0.047
-22	0.258	0.233	0.0120	0.047
-21	0.259	0.234	0.0121	0.047
-20	0.261	0.235	0.0121	0.047
-19	0.262	0.236	0.0122	0.047
-18	0.263	0.237	0.0122	0.046
-17	0.264	0.238	0.0123	0.046
-16	0.266	0.239	0.0123	0.046
-15	0.267	0.240	0.0124	0.046
-14	0.268	0.241	0.0124	0.046
-13	0.269	0.241	0.0124	0.046
-12	0.270	0.242	0.0125	0.046
-11	0.271	0.243	0.0125	0.046
-10	0.272	0.244	0.0126	0.046
-9	0.272	0.245	0.0126	0.046
-8	0.273	0.245	0.0126	0.046
-7	0.274	0.246	0.0127	0.046
-6	0.274	0.247	0.0127	0.046
-5	0.275	0.247	0.0127	0.046
-4	0.275	0.248	0.0128	0.046
-3	0.276	0.248	0.0128	0.046
-2	0.276	0.249	0.0128	0.046
-1	0.276	0.249	0.0128	0.046
0	0.277	0.250	0.0129	0.046

60 minutes after low tide

Time Interval	$\overline{R_t}$	SD	SE	RSE
0	0.277	0.250	0.0129	0.046
1	0.277	0.250	0.0129	0.046
2	0.277	0.250	0.0129	0.047
3	0.277	0.250	0.0129	0.047
4	0.277	0.251	0.0129	0.047
5	0.276	0.251	0.0129	0.047
6	0.276	0.251	0.0129	0.047
7	0.276	0.251	0.0129	0.047
8	0.275	0.251	0.0129	0.047
9	0.275	0.251	0.0129	0.047
10	0.274	0.251	0.0129	0.047
11	0.274	0.251	0.0129	0.047
12	0.273	0.250	0.0129	0.047
13	0.272	0.250	0.0129	0.047
14	0.271	0.250	0.0129	0.047
15	0.271	0.250	0.0128	0.047
16	0.270	0.249	0.0128	0.047
17	0.269	0.249	0.0128	0.048
18	0.267	0.248	0.0128	0.048
19	0.266	0.248	0.0128	0.048
20	0.265	0.247	0.0127	0.048
21	0.264	0.247	0.0127	0.048
22	0.262	0.246	0.0127	0.048
23	0.261	0.246	0.0126	0.048
24	0.259	0.245	0.0126	0.049
25	0.257	0.244	0.0126	0.049
26	0.256	0.243	0.0125	0.049
27	0.254	0.243	0.0125	0.049
28	0.252	0.242	0.0124	0.049
29	0.250	0.241	0.0124	0.050
30	0.248	0.240	0.0124	0.050
31	0.246	0.239	0.0123	0.050
32	0.244	0.238	0.0123	0.050
33	0.242	0.237	0.0122	0.051
34	0.240	0.236	0.0122	0.051
35	0.237	0.235	0.0121	0.051
36	0.235	0.234	0.0121	0.051
37	0.233	0.233	0.0120	0.052
38	0.230	0.232	0.0119	0.052
39	0.228	0.231	0.0119	0.052
40	0.226	0.230	0.0118	0.053
41	0.223	0.229	0.0118	0.053
42	0.221	0.228	0.0117	0.053
43	0.218	0.227	0.0117	0.054
44	0.216	0.226	0.0116	0.054
45	0.213	0.225	0.0116	0.055
46	0.210	0.224	0.0115	0.055
47	0.208	0.223	0.0115	0.055
48	0.205	0.222	0.0114	0.056
49	0.203	0.221	0.0114	0.056
50	0.200	0.220	0.0113	0.057
51	0.198	0.219	0.0113	0.057
52	0.195	0.218	0.0112	0.058
53	0.193	0.217	0.0112	0.058
54	0.191	0.216	0.0111	0.059
55	0.188	0.215	0.0111	0.059
56	0.186	0.214	0.0111	0.060
57	0.184	0.213	0.0110	0.060
58	0.182	0.213	0.0110	0.061
59	0.179	0.212	0.0110	0.061
60	0.177	0.211	0.0109	0.062

Table 12. Point values of the mean egress ratio ($\overline{R_t}$) at one-minute intervals for the Normal, ELOW egress model. Values for the mean, standard deviation of the data (SD), standard error of the mean (SE), relative standard error (RSE) for all time intervals between even half-hours were interpolated using a cubic spline function.

60 minutes prior to low tide

Time Interval	$\overline{R_t}$	SD	SE	RSE
-60	0.260	0.174	0.027	0.102
-59	0.263	0.174	0.027	0.101
-58	0.266	0.175	0.027	0.100
-57	0.268	0.175	0.027	0.100
-56	0.270	0.175	0.027	0.099
-55	0.273	0.175	0.027	0.098
-54	0.275	0.174	0.027	0.097
-53	0.277	0.174	0.027	0.096
-52	0.278	0.173	0.026	0.095
-51	0.280	0.173	0.026	0.094
-50	0.282	0.172	0.026	0.093
-49	0.284	0.171	0.026	0.092
-48	0.285	0.170	0.026	0.091
-47	0.287	0.169	0.026	0.090
-46	0.288	0.168	0.026	0.090
-45	0.289	0.167	0.025	0.089
-44	0.291	0.166	0.025	0.088
-43	0.292	0.165	0.025	0.087
-42	0.294	0.164	0.025	0.086
-41	0.295	0.163	0.025	0.085
-40	0.296	0.162	0.025	0.084
-39	0.298	0.161	0.025	0.083
-38	0.299	0.161	0.024	0.082
-37	0.300	0.160	0.024	0.082
-36	0.302	0.159	0.024	0.081
-35	0.303	0.159	0.024	0.080
-34	0.305	0.159	0.024	0.080
-33	0.307	0.158	0.024	0.079
-32	0.308	0.158	0.024	0.078
-31	0.310	0.158	0.024	0.078
-30	0.312	0.159	0.024	0.078
-29	0.314	0.159	0.024	0.077
-28	0.316	0.160	0.024	0.077
-27	0.318	0.161	0.025	0.077
-26	0.320	0.162	0.025	0.077
-25	0.322	0.163	0.025	0.077
-24	0.325	0.164	0.025	0.077
-23	0.327	0.166	0.025	0.077
-22	0.329	0.167	0.026	0.077
-21	0.332	0.169	0.026	0.077
-20	0.334	0.171	0.026	0.077
-19	0.336	0.173	0.026	0.078
-18	0.339	0.175	0.027	0.078
-17	0.341	0.177	0.027	0.078
-16	0.344	0.179	0.027	0.079
-15	0.346	0.181	0.028	0.079
-14	0.348	0.183	0.028	0.079
-13	0.351	0.185	0.028	0.080
-12	0.353	0.188	0.029	0.080
-11	0.355	0.190	0.029	0.081
-10	0.357	0.192	0.029	0.081
-9	0.359	0.194	0.030	0.082
-8	0.361	0.196	0.030	0.082
-7	0.363	0.198	0.030	0.083
-6	0.365	0.201	0.031	0.083
-5	0.367	0.203	0.031	0.084
-4	0.368	0.204	0.031	0.084
-3	0.370	0.206	0.031	0.085
-2	0.371	0.208	0.032	0.085
-1	0.372	0.210	0.032	0.086
0	0.373	0.211	0.032	0.086

60 minutes after low tide

Time Interval	$\overline{R_t}$	SD	SE	RSE
0	0.373	0.211	0.032	0.086
1	0.374	0.213	0.032	0.087
2	0.375	0.214	0.033	0.087
3	0.375	0.215	0.033	0.088
4	0.376	0.216	0.033	0.088
5	0.376	0.217	0.033	0.089
6	0.376	0.218	0.033	0.089
7	0.376	0.219	0.033	0.089
8	0.376	0.220	0.033	0.090
9	0.376	0.220	0.034	0.090
10	0.376	0.221	0.034	0.090
11	0.375	0.221	0.034	0.091
12	0.375	0.222	0.034	0.091
13	0.374	0.222	0.034	0.091
14	0.373	0.222	0.034	0.091
15	0.372	0.222	0.034	0.092
16	0.372	0.222	0.034	0.092
17	0.371	0.222	0.034	0.092
18	0.370	0.222	0.034	0.092
19	0.368	0.221	0.034	0.092
20	0.367	0.221	0.034	0.092
21	0.366	0.221	0.034	0.093
22	0.365	0.220	0.034	0.093
23	0.363	0.220	0.033	0.093
24	0.362	0.219	0.033	0.093
25	0.361	0.218	0.033	0.093
26	0.359	0.218	0.033	0.093
27	0.358	0.217	0.033	0.093
28	0.356	0.216	0.033	0.093
29	0.355	0.215	0.033	0.093
30	0.353	0.215	0.033	0.093
31	0.352	0.214	0.033	0.093
32	0.350	0.213	0.032	0.093
33	0.348	0.212	0.032	0.092
34	0.347	0.211	0.032	0.092
35	0.345	0.210	0.032	0.092
36	0.344	0.209	0.032	0.092
37	0.342	0.208	0.032	0.092
38	0.340	0.207	0.032	0.092
39	0.338	0.206	0.031	0.092
40	0.337	0.205	0.031	0.092
41	0.335	0.204	0.031	0.092
42	0.333	0.203	0.031	0.092
43	0.331	0.202	0.031	0.092
44	0.329	0.200	0.031	0.092
45	0.327	0.199	0.031	0.092
46	0.325	0.198	0.030	0.092
47	0.323	0.197	0.030	0.092
48	0.321	0.196	0.030	0.092
49	0.318	0.195	0.030	0.092
50	0.316	0.194	0.030	0.093
51	0.314	0.193	0.030	0.093
52	0.311	0.192	0.030	0.093
53	0.309	0.191	0.029	0.094
54	0.306	0.190	0.029	0.094
55	0.303	0.189	0.029	0.095
56	0.300	0.189	0.029	0.096
57	0.297	0.188	0.029	0.097
58	0.294	0.187	0.029	0.097
59	0.291	0.186	0.029	0.098
60	0.288	0.185	0.029	0.099

Table 13. Point values of the mean egress ratio ($\overline{R_t}$) at one-minute intervals for the Early Peak egress model. Values for the mean, standard deviation of the data (SD), standard error of the mean (SE), relative standard error (RSE) for all time intervals between even half-hours were interpolated using a cubic spline function.

60 minutes prior to low tide				
Time Interval	$\overline{R_t}$	**SD**	**SE**	**RSE**
-60	0.296	0.261	0.0221	0.075
-59	0.300	0.262	0.0222	0.074
-58	0.304	0.263	0.0223	0.073
-57	0.308	0.264	0.0223	0.072
-56	0.312	0.264	0.0224	0.072
-55	0.316	0.265	0.0225	0.071
-54	0.320	0.265	0.0225	0.070
-53	0.324	0.266	0.0225	0.069
-52	0.327	0.266	0.0226	0.069
-51	0.331	0.267	0.0226	0.068
-50	0.334	0.267	0.0227	0.068
-49	0.337	0.267	0.0227	0.067
-48	0.340	0.268	0.0227	0.066
-47	0.343	0.268	0.0227	0.066
-46	0.346	0.268	0.0227	0.065
-45	0.349	0.268	0.0228	0.065
-44	0.352	0.268	0.0228	0.064
-43	0.354	0.268	0.0228	0.064
-42	0.357	0.268	0.0228	0.064
-41	0.359	0.268	0.0228	0.063
-40	0.361	0.268	0.0228	0.063
-39	0.362	0.268	0.0228	0.063
-38	0.364	0.268	0.0228	0.062
-37	0.366	0.268	0.0228	0.062
-36	0.367	0.268	0.0228	0.062
-35	0.368	0.268	0.0228	0.062
-34	0.369	0.268	0.0228	0.062
-33	0.369	0.268	0.0228	0.062
-32	0.370	0.268	0.0228	0.062
-31	0.370	0.268	0.0228	0.062
-30	0.370	0.267	0.0228	0.062
-29	0.370	0.267	0.0228	0.062
-28	0.369	0.267	0.0228	0.062
-27	0.369	0.267	0.0228	0.062
-26	0.368	0.267	0.0228	0.062
-25	0.367	0.267	0.0227	0.062
-24	0.365	0.267	0.0227	0.062
-23	0.364	0.267	0.0227	0.063
-22	0.362	0.267	0.0227	0.063
-21	0.360	0.267	0.0227	0.063
-20	0.358	0.267	0.0227	0.064
-19	0.356	0.267	0.0227	0.064
-18	0.354	0.267	0.0227	0.064
-17	0.351	0.267	0.0227	0.065
-16	0.349	0.267	0.0227	0.065
-15	0.346	0.266	0.0226	0.066
-14	0.343	0.266	0.0226	0.066
-13	0.340	0.266	0.0226	0.067
-12	0.337	0.266	0.0226	0.067
-11	0.334	0.266	0.0225	0.068
-10	0.331	0.265	0.0225	0.068
-9	0.328	0.265	0.0225	0.069
-8	0.324	0.265	0.0224	0.069
-7	0.321	0.264	0.0224	0.070
-6	0.318	0.264	0.0224	0.071
-5	0.314	0.263	0.0223	0.071
-4	0.310	0.263	0.0223	0.072
-3	0.307	0.262	0.0222	0.072
-2	0.303	0.261	0.0222	0.073
-1	0.300	0.260	0.0221	0.074
0	0.296	0.260	0.0220	0.074

60 minutes after low tide				
Time Interval	$\overline{R_t}$	**SD**	**SE**	**RSE**
0	0.296	0.260	0.0220	0.074
1	0.292	0.259	0.0220	0.075
2	0.289	0.258	0.0219	0.076
3	0.285	0.257	0.0218	0.076
4	0.282	0.256	0.0217	0.077
5	0.278	0.255	0.0216	0.078
6	0.274	0.254	0.0215	0.078
7	0.271	0.252	0.0214	0.079
8	0.267	0.251	0.0213	0.080
9	0.264	0.250	0.0212	0.081
10	0.260	0.249	0.0211	0.081
11	0.257	0.247	0.0210	0.082
12	0.253	0.246	0.0209	0.083
13	0.250	0.244	0.0208	0.083
14	0.246	0.243	0.0207	0.084
15	0.243	0.241	0.0205	0.085
16	0.239	0.240	0.0204	0.086
17	0.236	0.238	0.0203	0.086
18	0.232	0.237	0.0202	0.087
19	0.229	0.235	0.0200	0.088
20	0.225	0.233	0.0199	0.088
21	0.222	0.232	0.0198	0.089
22	0.219	0.230	0.0196	0.090
23	0.215	0.228	0.0195	0.091
24	0.212	0.226	0.0193	0.091
25	0.208	0.225	0.0192	0.092
26	0.205	0.223	0.0190	0.093
27	0.202	0.221	0.0189	0.094
28	0.199	0.219	0.0187	0.094
29	0.195	0.217	0.0186	0.095
30	0.192	0.216	0.0184	0.096
31	0.189	0.214	0.0183	0.097
32	0.186	0.212	0.0181	0.097
33	0.183	0.210	0.0179	0.098
34	0.180	0.208	0.0178	0.099
35	0.177	0.206	0.0176	0.099
36	0.174	0.205	0.0175	0.100
37	0.171	0.203	0.0173	0.101
38	0.168	0.201	0.0171	0.102
39	0.165	0.199	0.0170	0.103
40	0.162	0.197	0.0168	0.103
41	0.159	0.195	0.0166	0.104
42	0.156	0.194	0.0165	0.105
43	0.153	0.192	0.0163	0.106
44	0.150	0.190	0.0161	0.107
45	0.147	0.188	0.0160	0.108
46	0.145	0.186	0.0158	0.108
47	0.142	0.184	0.0157	0.109
48	0.139	0.182	0.0155	0.110
49	0.137	0.181	0.0153	0.111
50	0.134	0.179	0.0152	0.112
51	0.131	0.177	0.0150	0.113
52	0.129	0.175	0.0148	0.114
53	0.126	0.173	0.0147	0.116
54	0.124	0.171	0.0145	0.117
55	0.121	0.169	0.0144	0.118
56	0.119	0.168	0.0142	0.119
57	0.116	0.166	0.0140	0.120
58	0.114	0.164	0.0139	0.122
59	0.112	0.162	0.0137	0.123
60	0.109	0.160	0.0136	0.124

Table 14. Point values of the mean egress ratio ($\overline{R_t}$) at one-minute intervals for the High Peak egress model. Values for the mean, standard deviation of the data (SD), standard error of the mean (SE), relative standard error (RSE) for all time intervals between even half-hours were interpolated using a cubic spline function.

60 minutes prior to low tide

Time Interval	$\overline{R_t}$	SD	SE	RSE
-60	0.270	0.229	0.0278	0.103
-59	0.274	0.229	0.0278	0.101
-58	0.278	0.230	0.0279	0.100
-57	0.282	0.230	0.0279	0.099
-56	0.286	0.231	0.0280	0.098
-55	0.290	0.232	0.0281	0.096
-54	0.294	0.232	0.0282	0.095
-53	0.298	0.233	0.0283	0.094
-52	0.302	0.234	0.0284	0.093
-51	0.306	0.235	0.0285	0.092
-50	0.310	0.236	0.0286	0.091
-49	0.315	0.237	0.0288	0.091
-48	0.319	0.238	0.0289	0.090
-47	0.323	0.239	0.0290	0.089
-46	0.327	0.240	0.0292	0.088
-45	0.331	0.242	0.0293	0.088
-44	0.335	0.243	0.0295	0.087
-43	0.340	0.244	0.0296	0.086
-42	0.344	0.245	0.0298	0.086
-41	0.348	0.246	0.0299	0.085
-40	0.351	0.248	0.0300	0.085
-39	0.355	0.249	0.0302	0.084
-38	0.359	0.250	0.0303	0.084
-37	0.363	0.251	0.0305	0.084
-36	0.367	0.252	0.0306	0.083
-35	0.370	0.253	0.0307	0.083
-34	0.374	0.254	0.0308	0.082
-33	0.377	0.255	0.0309	0.082
-32	0.380	0.256	0.0311	0.082
-31	0.383	0.257	0.0311	0.081
-30	0.386	0.258	0.0312	0.081
-29	0.389	0.258	0.0313	0.081
-28	0.392	0.259	0.0314	0.080
-27	0.394	0.259	0.0314	0.080
-26	0.397	0.260	0.0315	0.080
-25	0.399	0.260	0.0315	0.079
-24	0.401	0.261	0.0316	0.079
-23	0.403	0.261	0.0316	0.079
-22	0.405	0.261	0.0316	0.078
-21	0.407	0.261	0.0317	0.078
-20	0.409	0.262	0.0317	0.078
-19	0.410	0.262	0.0317	0.077
-18	0.411	0.262	0.0317	0.077
-17	0.413	0.262	0.0317	0.077
-16	0.414	0.262	0.0317	0.077
-15	0.415	0.262	0.0317	0.076
-14	0.416	0.262	0.0316	0.076
-13	0.416	0.262	0.0316	0.076
-12	0.417	0.262	0.0316	0.076
-11	0.417	0.262	0.0316	0.076
-10	0.418	0.261	0.0316	0.076
-9	0.418	0.261	0.0315	0.075
-8	0.418	0.261	0.0315	0.075
-7	0.418	0.261	0.0315	0.075
-6	0.418	0.261	0.0315	0.075
-5	0.418	0.261	0.0314	0.075
-4	0.417	0.261	0.0314	0.075
-3	0.417	0.260	0.0314	0.075
-2	0.416	0.260	0.0314	0.075
-1	0.415	0.260	0.0313	0.075
0	0.415	0.260	0.0313	0.076

60 minutes after low tide

Time Interval	$\overline{R_t}$	SD	SE	RSE
0	0.415	0.260	0.0313	0.076
1	0.414	0.260	0.0313	0.076
2	0.412	0.260	0.0313	0.076
3	0.411	0.260	0.0313	0.076
4	0.410	0.260	0.0313	0.076
5	0.408	0.260	0.0313	0.077
6	0.407	0.260	0.0313	0.077
7	0.405	0.260	0.0313	0.077
8	0.404	0.260	0.0313	0.078
9	0.402	0.261	0.0313	0.078
10	0.400	0.261	0.0313	0.078
11	0.398	0.261	0.0313	0.079
12	0.396	0.261	0.0313	0.079
13	0.393	0.261	0.0313	0.080
14	0.391	0.261	0.0313	0.080
15	0.389	0.261	0.0313	0.081
16	0.386	0.262	0.0313	0.081
17	0.384	0.262	0.0313	0.082
18	0.381	0.262	0.0314	0.083
19	0.379	0.262	0.0314	0.083
20	0.376	0.262	0.0314	0.084
21	0.374	0.263	0.0314	0.084
22	0.371	0.263	0.0314	0.085
23	0.368	0.263	0.0314	0.086
24	0.365	0.263	0.0314	0.086
25	0.362	0.263	0.0315	0.087
26	0.359	0.263	0.0315	0.088
27	0.356	0.263	0.0315	0.089
28	0.353	0.264	0.0315	0.089
29	0.350	0.264	0.0315	0.090
30	0.347	0.264	0.0315	0.091
31	0.344	0.264	0.0316	0.092
32	0.341	0.264	0.0316	0.092
33	0.338	0.264	0.0316	0.093
34	0.335	0.264	0.0316	0.094
35	0.332	0.264	0.0316	0.095
36	0.329	0.264	0.0316	0.096
37	0.325	0.264	0.0316	0.097
38	0.322	0.264	0.0316	0.097
39	0.319	0.264	0.0316	0.098
40	0.316	0.264	0.0316	0.099
41	0.312	0.263	0.0315	0.100
42	0.309	0.263	0.0315	0.101
43	0.305	0.263	0.0315	0.102
44	0.302	0.262	0.0314	0.103
45	0.298	0.262	0.0314	0.104
46	0.295	0.261	0.0313	0.105
47	0.291	0.261	0.0313	0.106
48	0.288	0.260	0.0312	0.107
49	0.284	0.259	0.0311	0.108
50	0.280	0.258	0.0310	0.110
51	0.276	0.257	0.0309	0.111
52	0.273	0.256	0.0308	0.112
53	0.269	0.255	0.0307	0.113
54	0.265	0.254	0.0305	0.114
55	0.261	0.253	0.0304	0.116
56	0.257	0.251	0.0302	0.117
57	0.253	0.250	0.0300	0.118
58	0.248	0.248	0.0298	0.120
59	0.244	0.246	0.0296	0.121
60	0.240	0.244	0.0294	0.123

Table 15. Point values of the mean egress ratio ($\overline{R_t}$) at one-minute intervals for the Twanoh State Park egress model. Values for the mean, standard deviation of the data (SD), standard error of the mean (SE), relative standard error (RSE) for all time intervals between even half-hours were interpolated using a cubic spline function.

60 minutes prior to low tide

Time Interval	$\overline{R_t}$	SD	SE	RSE
-60	0.156	0.129	0.0162	0.103
-59	0.159	0.131	0.0163	0.103
-58	0.161	0.132	0.0165	0.102
-57	0.164	0.133	0.0167	0.102
-56	0.167	0.135	0.0169	0.101
-55	0.169	0.136	0.0170	0.101
-54	0.172	0.138	0.0172	0.100
-53	0.174	0.140	0.0174	0.100
-52	0.177	0.141	0.0176	0.100
-51	0.180	0.143	0.0178	0.099
-50	0.183	0.144	0.0180	0.099
-49	0.185	0.146	0.0183	0.098
-48	0.188	0.148	0.0185	0.098
-47	0.191	0.149	0.0187	0.098
-46	0.193	0.151	0.0189	0.098
-45	0.196	0.153	0.0191	0.097
-44	0.198	0.155	0.0193	0.097
-43	0.201	0.156	0.0195	0.097
-42	0.203	0.158	0.0198	0.097
-41	0.206	0.160	0.0200	0.097
-40	0.208	0.162	0.0202	0.097
-39	0.210	0.163	0.0204	0.097
-38	0.213	0.165	0.0206	0.097
-37	0.215	0.167	0.0208	0.097
-36	0.217	0.168	0.0210	0.097
-35	0.219	0.170	0.0213	0.097
-34	0.221	0.172	0.0215	0.097
-33	0.222	0.173	0.0217	0.097
-32	0.224	0.175	0.0219	0.098
-31	0.226	0.177	0.0221	0.098
-30	0.227	0.178	0.0223	0.098
-29	0.228	0.180	0.0225	0.098
-28	0.229	0.181	0.0226	0.099
-27	0.230	0.183	0.0228	0.099
-26	0.231	0.184	0.0230	0.100
-25	0.232	0.185	0.0232	0.100
-24	0.233	0.187	0.0233	0.100
-23	0.233	0.188	0.0235	0.101
-22	0.234	0.189	0.0236	0.101
-21	0.234	0.190	0.0238	0.102
-20	0.234	0.191	0.0239	0.102
-19	0.235	0.192	0.0240	0.103
-18	0.235	0.193	0.0242	0.103
-17	0.235	0.194	0.0243	0.104
-16	0.234	0.195	0.0243	0.104
-15	0.234	0.195	0.0244	0.105
-14	0.234	0.196	0.0245	0.105
-13	0.234	0.196	0.0246	0.106
-12	0.233	0.197	0.0246	0.106
-11	0.233	0.197	0.0246	0.107
-10	0.232	0.197	0.0246	0.107
-9	0.231	0.197	0.0246	0.107
-8	0.230	0.197	0.0246	0.107
-7	0.230	0.197	0.0246	0.108
-6	0.229	0.196	0.0246	0.108
-5	0.228	0.196	0.0245	0.108
-4	0.227	0.195	0.0244	0.108
-3	0.226	0.195	0.0243	0.108
-2	0.225	0.194	0.0242	0.108
-1	0.223	0.193	0.0241	0.108
0	0.222	0.191	0.0239	0.108

60 minutes after low tide

Time Interval	$\overline{R_t}$	SD	SE	RSE
0	0.222	0.191	0.0239	0.108
1	0.221	0.190	0.0238	0.107
2	0.220	0.189	0.0236	0.107
3	0.218	0.187	0.0234	0.107
4	0.217	0.185	0.0231	0.106
5	0.216	0.183	0.0229	0.106
6	0.214	0.181	0.0227	0.105
7	0.213	0.179	0.0224	0.105
8	0.211	0.177	0.0221	0.104
9	0.210	0.175	0.0219	0.103
10	0.208	0.173	0.0216	0.103
11	0.207	0.170	0.0213	0.102
12	0.206	0.168	0.0210	0.101
13	0.204	0.165	0.0207	0.100
14	0.203	0.163	0.0204	0.100
15	0.201	0.161	0.0201	0.099
16	0.200	0.158	0.0198	0.098
17	0.198	0.156	0.0195	0.097
18	0.197	0.154	0.0192	0.097
19	0.195	0.151	0.0189	0.096
20	0.194	0.149	0.0186	0.095
21	0.193	0.147	0.0184	0.095
22	0.191	0.145	0.0181	0.094
23	0.190	0.143	0.0179	0.093
24	0.189	0.141	0.0176	0.093
25	0.188	0.139	0.0174	0.092
26	0.186	0.138	0.0172	0.092
27	0.185	0.136	0.0170	0.092
28	0.184	0.135	0.0169	0.091
29	0.183	0.134	0.0167	0.091
30	0.182	0.133	0.0166	0.091
31	0.181	0.132	0.0165	0.091
32	0.181	0.131	0.0164	0.091
33	0.180	0.131	0.0163	0.091
34	0.179	0.130	0.0163	0.091
35	0.178	0.130	0.0163	0.091
36	0.178	0.130	0.0162	0.092
37	0.177	0.130	0.0162	0.092
38	0.176	0.130	0.0163	0.093
39	0.176	0.130	0.0163	0.093
40	0.175	0.131	0.0163	0.093
41	0.175	0.131	0.0163	0.094
42	0.174	0.131	0.0164	0.095
43	0.174	0.132	0.0164	0.095
44	0.173	0.132	0.0165	0.096
45	0.172	0.132	0.0165	0.096
46	0.172	0.133	0.0166	0.097
47	0.171	0.133	0.0167	0.098
48	0.170	0.134	0.0167	0.099
49	0.169	0.134	0.0167	0.099
50	0.168	0.134	0.0168	0.100
51	0.167	0.135	0.0168	0.101
52	0.167	0.135	0.0168	0.101
53	0.165	0.135	0.0168	0.102
54	0.164	0.135	0.0168	0.103
55	0.163	0.135	0.0168	0.103
56	0.162	0.134	0.0168	0.104
57	0.160	0.134	0.0168	0.105
58	0.159	0.134	0.0167	0.105
59	0.157	0.133	0.0166	0.106
60	0.155	0.132	0.0165	0.106

Variance of the estimated all-day effort on a beach on a particular sampling day is approximated using the delta method (see Equation 9). The variance of the total season-long effort on a beach within any tide-day stratum is estimated with a two-stage variance formula (Cochran 1977; see Equation 14 in this report) that takes into account both the variation *between* sample days (essentially the variation between aerial counts of harvesters on the beach) and variation *within* sample days (i.e., the egress model variance). Based on initial empirical tests, virtually all the variance of season-long effort within a stratum is due to *between*-sample variance rather than *within*-sample variance. In other words, variation in the daily flyover counts of sport harvesters during the course of a season is usually much greater than the variance of mean egress ratios contained in the models.

Total season-long effort is estimated as the sum of the effort estimates from the three tide-day strata (see Equation 15); variance of total season-long effort is the sum of variance estimates from the three tide-day strata (see Equation 17).

5) Empirical comparison of current egress models vs. the former egress models

We empirically tested the effect of the current five egress models on annual estimates of sport effort by comparing two annual estimates of sport harvest effort: **(1)** the actual 2005 estimates of effort on public beaches, made using the two former egress models ("clam beach" and "oyster beach" models) used from 1996 through 2006, and **(2)** "new" 2005 effort estimates on the same beaches, made using the five egress models adopted for use in 2006.

The total annual effort estimate for all 140 beaches included in the comparison was 5% lower using the current models adopted for use in 2007. Of the 140 effort estimates, 102 estimates were higher using the current models, 31 estimates were lower using the current models, and seven beaches had annual effort estimates that were identical using the former and current models.

Of the 140 public beaches in the comparison, 130 beaches fell into the Normal category (i.e., daily effort expansions for the "new" estimates were made using the Normal, non-ELOW and Normal, ELOW egress models). Summing over all 130 Normal beaches, the current models produced a total annual effort estimate that was only 0.3% lower than that produced by the former models (73,284 harvester-days for the current models versus 73,478 for the former models). Sixty percent of the Normal beaches had effort estimates that differed by no more than 5% whether using the current and former models.

The difference between the two effort estimates on some Normal beaches was substantial, however, mostly depending on the timing of flight counts. For example, the current models produced effort estimates for the Oakland Bay public beaches that were 26-34% higher than those made by the former models (Table 16). As noted earlier in *Timing of Flight Counts*, flight counts at Oakland Bay generally occur an hour before the local low tide. At the –60 minute time interval, both the Normal, non-ELOW and Normal, ELOW models show mean egress ratios ($\overline{R}_t$) that are considerably lower than those in the former model (Figure 37, panel A); the effect of a lower mean egress ratio ($\overline{R}_t$) is a higher estimate of all-day effort. Similarly, the 2005 effort estimate using the current models for Silverdale Shoal (in Dyes Inlet, where flight counts are made on average 66 minutes before local low tide) was 32% higher than the actual effort estimate made using the former models.

Conversely, some Normal beaches had considerably lower 2005 effort estimates using the current models. The most extreme example (45% lower) was DNR-24 in southern Puget Sound, a beach where flight counts are generally made 10-30 minutes after local low tide. Figure 37, panel A, shows that in this range of time intervals, the Normal, non-ELOW model and former model egress curves lie very close to each other; but the Normal, ELOW model curve, on the other hand, is considerably higher than the former model curve at this time interval, resulting in much lower daily effort estimates within the ELOW stratum. The current models also produced a much lower effort estimate for Seal Rock FSC in northern Hood Canal. This difference is not related to flight timing, however, but is due to the fact that Seal Rock FSC effort was formerly estimated using the "oyster beach" egress model.

Effort estimates for the six Early Peak beaches averaged 9% higher when comparing results of the current models and the former models. Four of the Early Peak beaches (Fort Flagler State Park, Eagle Creek, Potlatch State Park and Potlatch DNR) had higher effort estimates using the current models, while two beaches (P.T. Ship Canal East and Lilliwaup State Park) had lower effort estimates using the current models (Table 16). Flight timing is again the main reason for the difference in the current and former model estimates. All four beaches with higher estimates using the current models are "late observation" beaches (i.e., flight counts are generally made 10-30 minutes after low tide). At these time intervals, the Early Peak model curve is considerably lower than the former model curve (Figure 37, panel A), resulting in much higher daily effort estimates. P.T. Ship Canal East, on the other hand, is an "early observation" beach, counted on average 10-30 minutes prior to low tide; this time interval corresponds closely with the highest point on the Early Peak model curve, accounting for the correspondingly lower estimate of effort when compared to the former model.

Table 16. Comparison of 2005 sport harvest estimates using the former and current egress models in Bivalve Regions 1, 5, 6, 7 and 8. This table only shows actively managed beaches included in the comparison. Effort is reported as total harvester days.

BIDN	Beach Name	Effort: old models	Effort: new models	Nominal change	Proportion change
	'Normal' Models				
250050	Sequim Bay State Park	1,517	1,588	71	0.05
250055	N Sequim Bay State Park	1,058	1,068	10	0.01
250400	Oak Bay County Park	564	573	9	0.02
250410	S. Indian Island County Park	4,778	5,021	243	0.05
250510	Wolfe Property State Park	3,938	4,316	378	0.10
250512	Shine Tidelands State Park	1,939	2,135	196	0.10
260380	Illahee State Park	1,638	1,687	49	0.03
270060	S. Zelatched Pt	332	328	-4	-0.01
270080	Toandos Peninsula State Park	1,355	1,352	-3	0.00
270170	Point Whitney Tidelands	1,706	1,766	60	0.04
270171	Point Whitney Lagoon	806	836	30	0.04
270202	Dosewallips State Park	212	193	-19	-0.09
270210	Seal Rock	4,076	2,269	-1,808	-0.44
270230	Kitsap Memorial State Park	1,598	1,666	67	0.04
270293	Triton Cove Tidelands	1,175	1,191	15	0.01
270380	DNR 44-A W Dewatto	919	986	67	0.07
270410	Scenic Beach State Park	81	83	2	0.03
270444	Potlatch East	30	33	3	0.10
270450	Cushman Park	1,570	1,590	20	0.01
270500	Quilcene Tidelands	4,160	4,214	54	0.01
270801	Dabob Broad Spit	986	979	-7	-0.01
270802	East Dabob	364	359	-5	-0.01
280680	Penrose Point SP	2,237	2,254	17	0.01
280711	North Bay	6,550	6,813	263	0.04
280975	Hope Island State Park	730	733	2	0.00
281020	NE Chapman Cove	17	22	6	0.34
281041	Oakland Bay Channel Flats	358	453	95	0.26
281043	Oakland Bay, Ogg	1,172	1,494	323	0.28
281050	Oakland Bay Reserve-E	16	21	5	0.32
281140	Frye Cove County Park	1,368	1,386	19	0.01
	'Early Peak' Model				
250260	Fort Flagler State Park	3,483	3,951	468	0.13
250470	P.T. Ship Canal East	1,759	1,445	-314	-0.18
270300	Eagle Creek	931	1,105	174	0.19
270440	Potlatch State Park	6,395	8,230	1,836	0.29
270442	Potlatch DNR	323	436	113	0.35
270310	Lilliwaup State Park	2,416	1,814	-601	-0.25
	'High Peak' Model				
270201	Dosewallips State Park	13,191	9,533	-3,658	-0.28
270286	Duckabush	10,253	7,537	-2,716	-0.26
270480	Rendsland Creek	357	275	-82	-0.23
	'Twanoh' Model				
270460	Twanoh State Park	4,822	4,000	-823	-0.17

The other Early Peak beach with a much lower effort estimate using the current models was Lilliwaup State Park. In this case, the reason for the difference was due to the fact that Lilliwaup effort was formerly estimated using the "oyster beach" egress model.

Effort estimates at all three High Peak beaches (Dosewallips State Park, Duckabush, and Rendsland Creek) were much lower using the current model (-28%, -26%, and –23%, respectively; Table 16). Figure 37, panel A, shows that the High Peak model curve is considerably higher than the former model for all time intervals from –60 to +60 minutes, thus accounting for the difference in effort estimates.

At Twanoh State Park, the current Twanoh model produced an estimate of 2005 effort that was 17% lower than the estimate using the former "oyster beach" model (Table 16). Figure 37, panel A, shows that the current Twanoh model curve is higher at all time intervals from –60 to +60 minutes, accounting for the difference in effort estimates.

We chose to make the empirical comparison above using 2005 aerial survey data, but we would expect roughly similar results (in terms of the *proportional* difference in annual effort estimates) using aerial survey data from *any* year. This is because the total number of flight counts, the distribution of flight counts within tide-day strata, and the timing of flight counts on individual beaches in 2005 are roughly similar for all years since the new flight route was established in 2002.

6) Summary of effort expansion factor analysis

Analysis focused on data gathered during 696 egress surveys on 39 public beaches, spanning a time period from 1989 to 2005. Analysis of flight timing confirmed that almost all flight counts occur within one hour of local low tide, allowing us to confine our analysis of egress survey data to that 2-hr time interval.

Based on the analysis of egress survey data, we recommended that the two former models used to expand aerial harvester counts from 1996 through 2006 (a "clam beach" model and an "oyster beach" model) be replaced with the five models shown in Figure 37: (1) two models for Normal beaches, which comprise roughly 90% of the public beaches currently observed during flights. One of the two models for Normal beaches expands harvester counts observed during the ELOW tide-day stratum (i.e., during weekend/holiday extreme low tides); the second model expands counts on Normal beaches made during the other two tide-day strata (called the "non-ELOW" strata), (2) a model for six Early Peak beaches, where the peak of all-day harvester effort occurs roughly 30 minutes prior to low tide, and is significantly higher than the peak effort on Normal beaches during non-ELOW tides, (3) a model for three High Peak beaches, where the peak of all-day harvester effort occurs near low tide but is significantly higher than the peak effort on Normal beaches, and (4) a model for Twanoh State Park, where the peak effort is significantly lower than on Normal beaches and occurs somewhat earlier.

We re-ran the 2005 sport effort estimation program using the five currently used models, and compared the results with actual 2005 effort estimates made using the former models. Overall, the new models produced an estimate of effort for Bivalve Regions 1, 5, 6, 7 and 8 that was 5% lower than the estimate using the former models. On Normal beaches, which comprise 130 of the 140 beaches flown in 2005, the overall difference between effort estimates using the current and former models was insignificant. On the six Early Peak beaches, the current model produced effort estimates that averaged 9% higher than those made with the former models. At the three High Peak beaches, the current models produced effort estimates that averaged 26% lower than those made with the former models. The current Twanoh State Park model produced an effort estimate that was 17% lower than that generated by the former "oyster beach" model.

We also recommended that estimates for mean and variance be generated at one-minute intervals along each of the egress models using interpolating cubic splines. This method is attractive primarily for its simplicity and the fact that it requires a minimum of assumptions about the "true" form of the model. It also preserves the values estimated at each 30-minute interval and reduces the possibility of systematic bias in harvest estimates at specific beaches, especially for beaches counted earlier in the flight route.

Finally, we provided a set of equations for estimating the variance surrounding daily effort estimates, as well as the variance for estimates of mean daily effort within each tide-day strata (see Part I of this report). These variance estimates permitted the calculation of 95% CIs on all sport effort and harvest estimates beginning in 2007.

7) Further studies

Results of our analysis highlight the need for continued refinement of egress models, and reinforce the findings of the 1996 Biometric Review (Tagart et al. 1996) which recommended repeating egress studies from "time to time." For example, the ten beaches currently assigned to the Early Peak, High Peak and Twanoh egress models comprise only 25% of all actively managed beaches, but accounted for 48% of harvester effort in 2005. In absolute percentage terms (ignoring whether the change was positive or negative) the median change in estimated harvest effort at these ten beaches was approximately 25%. Changes of this magnitude have a significant impact on management decisions in terms of reducing or extending harvest opportunities. Given the potential for similar improvements, we therefore plan to continue conducting egress surveys. The most pressing need is for additional data within the ELOW tide-day stratum and at beaches where a majority of harvesters tend to arrive *after* the low tide. Additional data will also be needed for Oakland Bay to determine if a separate egress curve is appropriate.

In addition to compiling new data, we are currently developing a set of simulation tools using the R programming language. These tools will allow us to further refine egress models. Egress data are ideally suited for simulation studies because the data represent, in essence, a complete census of harvester effort for the days sampled. We can therefore use our growing database of egress surveys as a pool from which to draw simulated flyover counts and then compare our estimates of harvester effort using candidate egress models with the actual census counts recorded during egress surveys.

To simulate effort, the program we are developing randomly draws a "typical" year's worth of instantaneous flyover counts (variable E_t in Equation 8) from each beach where we have sufficient egress data in each stratum. "Typical" in this respect means that the number and timing of counts is representative of actual flyover counts collected during a full year of aerial surveys. Each instantaneous count is then multiplied by the appropriate egress expansion factor, producing simulated estimates of all-day effort. These simulated all-day effort estimates are then compared with the actual all-day census counts recorded during each of the sub-sampled egress surveys. The simulation program also allows us to calculate what the expansion factor *should* have been in order to equal the exact all-day harvester counts recorded during the egress surveys.

For initial trials of the simulation program, we defined "sufficient egress data" as at least ten egress surveys for each beach, and at least two surveys per tide-day stratum. We were consequently able to simulate harvester effort on ten beaches belonging to the Normal, non-ELOW model. A total of 5,000 "years" of simulated data were generated and compared.

Results of these initial trials validated the use of the current Normal, non-ELOW model for the group as a whole, but also indicated that specific beaches will need to be surveyed more intensively to determine if separate egress models are justified. Table 17 shows the group and individual results. For the group as a whole, the Normal, non-ELOW model over-estimated effort by only 45 harvesters (a 0.6% increase). On a beach-specific basis, however, results suggested there was considerable room for improvement. Of greatest concern were beaches at Illahee State Park and Oakland Bay. Here, results indicated that the current model may under-estimate total effort by as much as 30% and 34% respectively. Given that public beaches are managed as separate entities, it is the beach-specific results that are most relevant.

Table 17. Results of simulation trial for the Normal, non-ELOW model. The trial was confined to beaches with at least ten egress surveys, and at least two surveys in each tide-day stratum. Effort is given in harvester-days. Five thousand 'years' of simulated effort numbers were generated for comparisons.

Beach Name	Effort: census	Effort: simulated	Nominal change	Proportion change
Sequim Bay State Park	906	970	64	0.066
Oak Bay County Park	494	599	105	0.176
Wolfe Prop. State Park	534	743	209	0.281
Shine Tidelands State Park	844	1002	158	0.158
Illahee State Park	840	648	-192	-0.296
Seal Rock	2633	2292	-341	-0.149
Kitsap Memorial State Park	311	324	12	0.038
Triton Cove Tidelands	330	433	103	0.238
DNR-44A W. Dewatto	328	359	31	0.086
Oakland Bay, Ogg	411	307	-105	-0.341
	7631	**7676**	**45**	**0.006**

A detailed look at results for Oakland Bay (Table 18) illustrates two specific issues that further studies will need to address. The first issue is inadequate sample size. The Oakland Bay simulation results were derived by resampling from 16 egress surveys. A separate egress model for Twanoh State Park was only possible because a sufficient sample size of egress surveys (n = 64) were available. Additional surveys will need to be conducted before models can be optimized for specific beaches. The second issue is whether the arithmetic mean provides the best estimate of the egress ratio ($\overline{R}_t$). Values for the simulated ratio ($sim\overline{R}_t$) suggested that an optimized egress curve should be based on values lower than those derived using the arithmetic mean ($oak\overline{R}_t$), at least for time intervals where a majority of flight counts normally occur. Egress data normally include a high number of zero values (Figure 10, panel A). Consequently, a robust mean that discounts the effect of extreme values in the tails of the frequency distribution may be more appropriate. Given a sufficient sample size of egress surveys, simulation will be especially useful to validate whether the arithmetic, or some alternative robust mean, provides the best estimates for beach-specific egress curves.

Table 18. Detailed results of simulation trial for the Normal, non-ELOW model applied to Oakland Bay data. Results are reported for each time interval where flyover counts normally occur. Effort is given in harvester-days. Values in the final two columns are for the mean, and simulated, egress ratios respectively. These were derived from Oakland Bay data only. The simulation results were derived by resampling from a pool of 16 egress surveys. Five thousand 'years' of simulated effort numbers were generated for comparisons.

Time Interval (*t*)	Flyover counts	Effort: census	Effort: Simulated	Nominal change	Proportion change	$\overline{R_t}$	$sim\ \overline{R_t}$
-90	3	48	41	-7	-0.17	0.135	0.124
-60	17	255	195	-60	-0.31	0.178	0.145
-30	4	54	36	-18	-0.51	0.220	0.161
0	3	38	19	-19	-0.95	0.140	0.151
30	1	16	16	-1	-0.04	0.197	0.204
	28	**411**	**307**	**-105**	**-0.34**		

Part V: Analysis Of Plus Tides Effort

Daily recreational effort on "plus tides" (tides $\geq$ 2.0 ft and < 4 ft) was estimated until 2003 for each beach as 16.8% of the mean unstratified daily effort on high tides (0.0 to 1.9 ft). Because no detailed, quantitative justification for this estimate was available, however, we conducted a new analysis using all available plus tides effort data. In this analysis we asked the following questions:

1) Should daily plus tides effort be calculated as 16.8% of the unstratified mean daily effort on high tides?

2) If not, then what is a more appropriate constant to apply?

Methods

Available Data

Aerial surveys to estimate plus tides effort were conducted in 1993 and 1994. There were 13 flights in 1993 and 14 flights in 1994 that were scheduled during plus tides. As might be expected, few harvesters were counted at this stage of the tide. Flight counts were typically zero on most beaches. Nearly all of the observed harvest activity occurred on beaches categorized as actively managed beaches. For this reason, we confined our analysis to data from actively managed beaches. The instantaneous count of harvesters (variable E_t in Equation 8, equivalent to the SAS harvest program variable *uclam*) was used in all analyses. Only data from beaches that were open to both clams and oysters were used.

Analysis

To determine if the former 16.8% constant was appropriate, we calculated the ratio between mean daily effort observed during plus tides (2.0 to 3.9 ft), and mean daily effort observed during high tides (0.0 to 1.9 ft) for each beach in the dataset. Ratios were only computed for beaches where effort was observed on at least five separate occasions on both high tides and plus tides in 1992 and 1993 (i.e., we used only non-zero ratios). Though this admittedly biased the estimate towards ratios expected on higher use beaches, it was assumed that ratios for low-use beaches would be similar given a sufficient amount of data, and that this method would be less likely to underestimate true mean daily effort on plus tides. Another practical consideration was that dividing by zero is undefined.

After all non-zero ratios were calculated, a grand mean of all ratios was computed and compared to the 16.8% constant previously used to estimate plus tides effort. The final mean of ratios was computed as:

$$\text{Mean plus tides ratio} = \frac{\sum_{b=1}^{L} p_b / h_b}{N_b} \qquad (37)$$

where

p_b = mean unstratified daily effort on plus tides (2.0 to 3.9 ft) for a given beach b

h_b = mean unstratified daily effort on high tides (0.0 to 1.9 ft) for a given beach b

N_b = total number of beaches with non-zero ratios

L = total number of non-zero ratios computed

Because the ratios between use on *high* tides versus *plus* tides varied greatly from one beach to another, we also computed ratios between effort on *plus* tides versus effort on *all* tides less than 2.0 ft. It was assumed that this would provide a more stable and lower variance estimate of the true ratio. The formula used was identical to Equation 37 above, except that h_b = mean unstratified daily effort on all tides (< 2.0 ft) for a given beach b.

Results

Analysis using a paired comparison of effort on plus tides versus effort on high tides for each beach with non-zero ratios in the 1992-1993 data set indicated that the plus tides constant of 16.8% needed to be revised. The grand mean of ratios was 0.87, indicating that 87% of effort on high tides was present on plus tides. The coefficient of variation (CV) for this estimate was 1.39, however, indicating that precision could be improved. Several outlier values also cast doubt on the accuracy of this estimate.

Analysis comparing *plus* tides effort with effort on *all* tides less than 2.0 ft provided a more precise estimate (Appendix Table 9). The grand mean of ratios in this analysis was 0.1656 indicating that roughly 16% of the effort on all tides less than 2.0 ft occurred on plus tides. The CV was 0.63. This was still high, but more precise than using high tide effort counts as a baseline of comparison, which resulted in a CV of 1.39.

Because of the high variance in the estimate and possible influence of outliers, we also computed the median for the ratios. The median value was 0.1542 (Appendix Table 9) and supported our use of the arithmetic mean as a relatively robust measure of centrality.

To determine what effect implementation of the new constant would have on effort estimates for selected beaches in Puget Sound and Hood Canal, we calculated total 2002 recreational effort using both models. Table 19 shows the results on six important public beaches. The mean change for the six beaches was a 2.9% increase in the total effort estimate.

Table 19. Comparison of the current and former plus tide constants used in estimating recreational effort on selected beaches using 2002 data. The former constant estimated mean daily plus tide effort as 0.168 x unstratified mean daily effort on all sampled tides from 0.0 to 1.9 ft. The new constant estimates mean daily plus tide effort as 0.16 x unstratified mean daily effort on all sampled tides. Plus tides are all tides from 2.0 to 3.9 ft. Effort estimates include plus tides effort and winter effort (where applicable).

BIDN	Beach Name	Effort: New constant	Effort: Old constant	Nominal change	Proportion change
250260	Fort Flagler SP	6,852	6,618	234	0.035
270200	Dosewallips SP	18,640	18,280	360	0.020
270440	Potlatch SP	19,732	19,013	719	0.038
270500	Quilcene Bay Tidelands	4,608	4,522	86	0.019
280710	North Bay	4,384	4,250	134	0.032
281043	Oakland Bay Ogg	1,659	1,610	49	0.030
		55,875	54,293	1,582	0.029

Summary of plus tides analysis

The first question we asked in this analysis was: Should daily *plus* tides effort be calculated in the former manner as 16.8% of the unstratified mean daily effort on *high* tides? Results indicated that a more precise estimate (i.e., an estimate with a lower CV) of plus tides effort could be obtained by comparing effort on *plus* tides with effort on *all* tides less than 2.0 ft. The analysis also indicated that the former plus tides model probably underestimated true plus tides effort, especially on higher use beaches that are of greater concern from a management perspective.

The second question we asked was: What is a more appropriate constant to apply? Results of the second phase of this analysis indicated that a reasonable constant to use in calculating *plus* tides effort was 16% of the unstratified mean daily effort on *all* tides less than 2.0 ft. Implementation of this constant resulted in a relatively modest 2.9% increase in mean total estimated effort for the six beaches tested, when compared to the former constant.

Though the 16% constant provided a more precise estimate of plus tides effort, the CV of 0.63 indicated that additional plus tides effort data needs to be collected so that the model can be further improved in coming years.

Part VI: Analysis Of Catch Per Unit Effort Estimation

Recreational catch per unit effort (CPUE, the average weight of clams or number of oysters taken per harvester-day) is estimated from creel surveys on all actively managed beaches unless otherwise agreed by the state and treaty tribes. Creel surveys are conducted for a 4-hr period straddling the local time of low tide. Whenever possible, all recreational harvesters exiting the beach during this 4-hr time period are interviewed at the end of their fishing trip. The creel surveys provide only an estimate of mean daily CPUE by species; they do not supply any data used in estimating harvester effort.

Prior to 2003, creel sampling was stratified by three tide heights: **(1) Extreme Low**, -2.0 ft and below, **(2) Low**, -0.1 to -1.9 ft, and **(3) High**, 0.0 to 1.9 ft. Creel surveys were formerly assigned to one of these three creel strata according to tide height. Survey dates were chosen randomly from available tides within each stratum.

The daily CPUE for each species on a beach was formerly estimated for each creel survey day in tide stratum *h* (**Extreme Low**, **Low**, or **High**) by dividing the total daily catch (pounds per species for clams, or number of oysters) by the total number of harvesters interviewed:

$$CPUE_{h,d} = \frac{\sum_{i=1}^{n_d} catch_{h,i,d}}{\sum_{i=1}^{n_d} harvester_{h,i,d}} \qquad (38)$$

where

$CPUE_{h,d}$ = the daily CPUE on day *d* in tide stratum *h*

$catch_{h,i,d}$ = the catch (pounds for clams, numbers for oysters) by the *i*th harvester on day *d* in tide stratum *h*

$harvester_{h,i,d}$ = the *i*th harvester interviewed on day *d* in tide stratum *h*

n_d = the total number of harvesters interviewed on day *d*

A separate $CPUE_s$ was calculated for each species (Manila clams, native littlenecks, cockles, butters, geoducks, etc.). Only one $CPUE_s$ per species was calculated for each creel survey day on a beach. This “per-day” or “ratio of means” estimator involves less bias and has a truer confidence interval than the “per-angler” or “mean of ratios” estimator when fishers are sampled with equal probability at the completion of their fishing trip (Jones et al. 1995).

On an individual beach during the year, the stratified mean CPUE ($\overline{CPUE}_h$) for each tide stratum *h* (and species) was formerly calculated as the average of all the daily CPUE estimates for that tide stratum and species:

$$\overline{CPUE}_h = \frac{\sum_{d=1}^{n_h} CPUE_{h,d}}{n_h} \qquad (39)$$

where

$\overline{CPUE}_h$ = the mean CPUE for tide stratum *h*

$CPUE_{h,d}$ = the daily CPUE for day *d* in tide stratum *h*

n_h = the number of days sampled in stratum *h*

Sample size per stratum (n_h) was recommended by the 1997 appendix to the Bivalve Management Agreement, which stated: "The objective is to sample each strata[*sic*] a minimum of three times during each harvest season ... on a beach." With three tide strata, the resulting sample size was therefore nine creel surveys per beach per season.

When $\overline{CPUE}_h$ for a tide stratum could not be calculated because of missing data (for example, if no extreme low tides were sampled on a given beach), substitution values were used. When beach-specific CPUE estimates were missing, values from the previous year were substituted; if a previous-year value was not available for the individual beach, a substitution from two years earlier was used. If no value was available from either the previous year or two years prior, a mean *regional* value was applied. This regional substitute value was generated for each stratum from the pool of all beaches in the Bivalve Region.

The 1997 appendix to the Bivalve Management Agreement provided the following rationale for stratifying CPUE by tide height: "These strata were selected based on the analysis of historic data from previous flight and creel surveys which showed that variation in fishing effort and CPUE is related to differences in tide height and day of week." This analysis of historic data, however, is no longer available.

In this analysis, we asked the following questions:

1) Were the former tide strata advantageous in estimating mean CPUE for clams and oysters? (Specifically, does stratification provide more precise estimates of mean CPUE than a non-stratified approach?)

2) If the former tide strata were not advantageous, was there other tide or tide and day-of-week strata that might provide more precise estimates of mean CPUE? In particular, would *two* strata consisting of weekend extreme low (ELOW) tides and all other tide-day strata combined be advantageous for CPUE estimation?

3) If it is not advantageous to stratify mean CPUE by tide height, what is the optimum sample size (number of creel sample days) per beach to obtain a level of precision which is useful for management?

4) Does mean CPUE for managed species (Manila clams, native littlenecks, and oysters) vary from year to year on individual beaches? If not, is it advantageous to create a pooled estimate of mean CPUE by averaging several years of data?

Methods

Available Data

When testing differences in CPUE by tidal height, we used CPUE data by beach and species from all creel surveys conducted in 1998, 1999, and 2000 in all eight Bivalve Regions. Although we make inferences in this report only for Regions 1, 5, 6, 7 and 8, we analyzed creel survey data for some beaches in Regions 2, 3 and 4 in order to increase sample size (i.e., total number of beaches). This was particularly important when analyzing butter clam CPUE, since few beaches in Regions 1, 5, 6, 7 and 8 are dominated by butter clams. When testing differences in CPUE by year, we analyzed CPUE data by beach and species from all creel surveys conducted in 1998, 1999, 2000, and 2001. The "per-day" estimates of $CPUE_{h,d}$ (Equation 38) for each beach-day were derived by running a short, amended segment of the SAS Quarterly Harvest program and adding an output statement to format the intermediate SAS file named "Creel" as a *.dbf* permanent file. $CPUE_{h,d}$ for Manila clams, native littlenecks, and butter clams (as weight in pounds per harvester) are listed in the output as MAN_WT, NAT_WT, and BUT_WT. $CPUE_{h,d}$ for Pacific oysters (as number of oysters per harvester) is listed in the subroutine output as OYS_ . We also calculated a $CPUE_{h,d}$ for Manila clams and native littlenecks combined, which we listed as LNCK_WT.

Season regulations were considered in the analysis, just as they are in the current harvest estimation procedure. For example, stratified mean CPUEs ($\overline{CPUE_h}$) for Manila clams, native littlenecks, and butter clams were only calculated using creel survey days when the season was open for clams. In other words, the $CPUE_{h,d}$ for clams on survey days when the clam season was closed was considered a missing value, not a zero. In analyses of oyster CPUE, we did not separate the data for "clamming open" and "clamming closed" seasons. Admittedly, these season changes may have affected oyster CPUE on those beaches where they occurred, but we chose to ignore these instances to maintain viable sample sizes for oyster CPUE, and to keep the analyses simple.

Objectives and Test Procedures

1) Analysis of Variance (CPUE Differences by Tide Strata)

ANOVA was used to determine if the former three tide strata decreased the variance of mean CPUE for managed species (Manila clams, native littlenecks, and Pacific oysters). Stratification is useful only if the variance *among groups* (in this case the former tide strata) is greater than variance *within groups*. If not, stratification is not useful, and actually decreases the precision of our estimated mean CPUE. We tested the following hypothesis:

H_0: Variance of stratified mean CPUE ($\overline{CPUE_h}$) within groups (tide strata) is equal to or greater than the variance among groups.

H_A: Variance of $\overline{CPUE_h}$ among groups (tide strata) is greater than variance within groups.

For each sampled beach, we used a single factor ANOVA to compare $\overline{CPUE_h}$ by tide strata, and tested the null hypothesis of no tide effect with a variance-ratio test (*F*-test) with $\alpha = 0.05$. ANOVAs were conducted using PopTools, a free statistical add-in for Excel available from http://www.cse.csiro.au/CDG/poptools/

Since each combination of beach, species and year produced a separate hypothesis test, it was likely that there would be some mixture of significant and non-significant tests results. There is no standard statistical procedure for dealing with such a mixture of test results. However, for a stratification variable to be useful in a long-term survey, it must be persistent across years. Thus, we only considered the tide strata to be useful for a managed species if the null hypothesis (i.e., no tide effect) was rejected in more than one of the three years. Moreover, a stratification variable which produced significant test results only on certain beaches and only for certain species was not likely to be useful on a broad-scale survey involving many beaches and several key species. In short, our conclusions favored the null hypothesis (i.e., the former tide strata were *not* useful) unless the data argued *overwhelmingly* to the contrary.

The following procedure was used in the tests and subsequent analyses:

a) Test CPUE tide stratification by beach, by species, and by year. For example, we conducted 12 total ANOVAs on Wolfe Property State Park CPUE data from 1998, 1999, and 2000 (one ANOVA each for Manila clams, native littlenecks, Manila clams *plus* native littlenecks, and oysters *each year*). The number of ANOVAs necessarily varied by beach, because not all beaches contained the same complement of species and because not all beaches were sampled every year. On most beaches it was possible to compare all three tide strata each survey year, but in some cases a particular tide stratum was either not sampled at all on a beach in a given year, or was sampled only once in a given year. In these cases, it was obviously impossible to conduct an ANOVA using all three tide strata, so only those tide strata sampled at least twice in the year were tested.

b) In beach-species tests for a particular year where the null hypothesis was rejected (i.e., where tide effects on $\overline{CPUE_h}$ were significant), we compared the tests for other years on the same beach to see if the pattern was persistent across years. If a stratification variable is not persistent across years it is not likely to be useful in a long-term sampling program.

We chose not to estimate the statistical power ($1 - \beta$) of the ANOVA tests for tide effects, because power is not relevant in the context of the objectives of this study. Power tests estimate the probability of making a Type II error (in our case, the probability of failing to reject the null hypothesis of no tide effects if in fact there were tide effects). It is important to note, however, that *our objective was not to determine if tide effects on CPUE truly existed*; instead, we were primarily interested in knowing if our former tide stratification improved the precision of the CPUE estimate given the former and current levels of sampling. In other words, we wanted to know *if our creel survey methods were capable of detecting tide effects at current sample sizes*. If not –if we failed to reject the null hypothesis – then from a practical standpoint it was immaterial whether or not our failure to reject H_0 was the result of low statistical power. Failing to reject H_0 with low power, for example, would not answer any questions about potential tide effects on CPUE, but it *would* clearly provide evidence that the former tidal stratification was not improving the precision of the CPUE estimate.

2) Analysis of Alternate Tide or Day Strata

Using the pooled data from all three years, we prepared graphs of "per-day" CPUE ($CPUE_{h,d}$) versus tide height on important beaches. These graphs might suggest alternative tide strata that could be tested with the ANOVA procedure to determine if they were more useful than the former three tide strata.

Although creel surveys were not formerly stratified by weekend-weekday, we examined recent creel data to determine if mean CPUE varied significantly between weekend and weekday, using a one-way ANOVA to test the hypothesis that mean CPUE was the same for both strata. Because there were rarely enough data within a single year to test weekend-weekday differences, we pooled all 1998, 1999, and 2000 creels for this analysis.

Because the effort analysis in Part III of this report showed that the weekend extreme low stratum (ELOW) was advantageous for *effort* estimation, we tested CPUE for the ELOW stratum against CPUE for all non-ELOW creel surveys, again using a one-way ANOVA. Because not enough data were available within a single year to test the ELOW stratum, we pooled all 1998, 1999, 2000, and 2001 data for this analysis.

3) Monte Carlo Simulation of Minimum Sample Size

Sample size (i.e., the number of days that creel surveys are performed on a particular beach per season) was determined prior to 2003 by the twin constraints of tide stratification and available staffing. An absolute minimum of six creel surveys had to be performed on each beach in order to mathematically obtain variance estimates for $\overline{CPUE_h}$ within each of the former three tidal strata; in other words, at least two creel surveys per tide stratum. But if tide strata were eliminated as a consideration, we have more flexibility in recommending a sample size expected to provide a desired level of precision. Without tide strata, the absolute minimum sample size is two creel surveys per beach; and a more meaningful variance estimate would be produced with a minimum sample size of three creel surveys per beach.

In suggesting the minimum sample size for estimating mean CPUE, we used a relative standard error (RSE) of 0.20 as a desired level of precision. We set this desired level of precision because it corresponds roughly with the level of precision of recreational *effort* estimates. For example, Figure 5 suggests that the average proportion error of effort estimates will be in the range of 0.40 – 0.30 with sample sizes of 30 to 45 flights. Thus, RSEs on the effort estimates – which are roughly half the value of the proportion error – would be in the range of 0.20 – 0.15. The variance of the harvest estimate on a beach is the variance of products (effort x CPUE; see Equation 22). A variance of products tends toward the term with the *highest* variance, so it is desirable for the variance of mean CPUE to be roughly equal or lower than the variance of mean effort. This desired level of precision is also common in other creel surveys. Precision in the range of 0.20 to 0.40 is considered adequate for management of WDFW warmwater and resident trout sport fisheries (Hahn et al. 2000), and Ontario has adopted a goal of 0.20 for its sport fishery creel surveys (Lester et al. 1991).

To provide some idea of former sample sizes and the current precision of estimates of mean CPUE, we calculated the relative standard error (RSE) of mean CPUE for 18 of the most important clamming beaches in all eight Bivalve Regions, using year 2000 creel survey data in most cases. Where creel surveys were not performed on a beach in year 2000, we used either 1999 or 2001 data. We calculated CPUE and its RSE only for the dominant clam species on each of the 18 beaches. On each of the beaches, we also calculated how important the "dominant" clam species was in comparison to the other clam species in the creel. This measure of "% dominant species in creel" was calculated as:

$$\%D = \frac{\sum_{i=1}^{n_d} d_i}{\sum_{i=1}^{n} T_i}(100) \qquad (40)$$

where

$\%D$ = the percentage of dominant species clams observed in the creel during the year compared to all clams observed in the creel during the year.

d_i = the ith dominant species clam in the creel

T_i = the ith clam of any species in the creel

n_d = the number of dominant species clams observed in the creel

n = the number of all clams observed in the creel

In order to show how sample size affects precision, we prepared graphs of the RSE of mean CPUE versus sample size, eliminating tide height as a stratification variable, and using only the unstratified daily CPUE values for the dominant clam species in the creel. For this analysis, we selected ten important Puget Sound beaches as examples. These particular beaches were chosen as examples because they typically account for a high proportion of the total Puget Sound recreational catch. The expected RSE for sample sizes ranging from two to 25 creel surveys was graphed for each beach. Expected RSE for a given sample size *n* was calculated as the mean RSE of 1,000 bootstrap replicates of size *n*. The bootstrap replicates were resampled with replacement from all unstratified daily values of CPUE on the beach from all creel surveys in 1998 through 2001. Mean CPUE, its SE and RSE were then calculated for each bootstrap replicate, providing 1,000 values of RSE for each sample size. Bootstrap resampling and Monte Carlo analysis were performed with PopTools, a free statistical add-in for Excel available from http://www.cse.csiro.au/CDG/poptools/

4) Analysis of Variance (CPUE Differences by Year)

ANOVA was used to test whether there was a significant difference in unstratified mean CPUE ($\overline{CPUE}$) for various species from year to year on individual beaches. We tested the following hypothesis:

H_0 : $\overline{CPUE}_{2001} = \overline{CPUE}_{2000} = \overline{CPUE}_{1999} = \overline{CPUE}_{1998}$

H_A: $\overline{CPUE}$ for the four years are not all equal.

Not all beach-species combinations provided enough data with which to compare CPUE over all four years. In such cases, those years providing at least two estimates of daily CPUE were tested with a modified version of H_0 above. For each sampled beach and important species, we used a single factor analysis of variance (ANOVA) to compare $\overline{CPUE}$ by year, and tested the null hypothesis with a variance-ratio test (*F*-test) with $\alpha = 0.05$. ANOVAs were conducted using PopTools, a free statistical add-in for Excel available from http://www.cse.csiro.au/CDG/poptools/

Results

1) Analysis of Variance (CPUE Differences by Tide Strata)

Appendix Table 10 shows the summary ANOVA results (by creel survey year) in which the variance of mean CPUE for Manila clams was tested with the former tide strata. A total of 42 ANOVAs were performed on data from 22 beaches. Tide strata were a significant factor in CPUE (i.e., the null hypothesis was rejected) in only three of the 42 ANOVAs : Wolfe Property State Park in year 2000, Birch Bay State Park in 1998, and DNR 44-A W. Dewatto in 1998. Neither Birch Bay nor Dewatto are important “Manila beaches;” Manila clams typically make up less than 5% of the total littleneck harvest (Manila and native littlenecks combined). Wolfe Property State Park was surveyed all three years, and the remaining two ANOVAs did not produce significant test results. However, because all three tide strata could not be compared across all three years on Wolfe Property (there were not enough data from extreme minus tides in two of the three years), we cannot make any inferences one way or the other about persistent tide strata patterns across years at Wolfe Property. A closer examination of the 2000 creel survey data at Wolfe suggests the reason for the significant test result that year: All three tide strata were sampled three times each in 2000, and it was the low mean CPUE for the extreme low tides which resulted in the significant *F*-test at Wolfe. On one of the three extreme low tide days sampled, only two harvesters were interviewed, both primarily after oysters. On the other two extreme lows, a large party of harvesters was targeting cockles rather than Manila clams (CPUE for cockles on both days was roughly 15 pounds, unusually high for any beach). Thus, the single significant test result for a “Manila beach” appears to be largely the result of anomalous circumstances in year 2000.

Appendix Table 11 shows the summary ANOVA results (by creel survey year) for native littleneck CPUE. A total of on 58 ANOVAs were performed on data from 29 beaches. Tide strata were a significant factor in CPUE in only two of the 58 ANOVAs : Potlatch State Park in 1999, and Ala (Ben Ure) Spit in 1998. At Ala Spit, Manila clams are an insignificant component of the clam catch. Potlatch was creel surveyed all three years, and the ANOVAs in 1998 and 2000 were not significant. Therefore, the tide strata differences that produced a significant test result in 1999 at Potlatch were not persistent across years.

Appendix Table 12 shows the summary ANOVA results (by creel survey year) for *combined* Manila *and* native littleneck CPUE. A total of on 38 ANOVAs were performed on data from 19 beaches. Tide strata were a significant factor in CPUE in only two of the 38 ANOVAs : Wolfe Property State Park in year 2000 and Potlatch State Park in 1999. Obviously, these results stem from the Manila clam differences on Wolfe Property in 2000 and the native clam differences at Potlatch in 1999. Note that at Birch Bay, where the 1998 ANOVA was significant for Manila clams, the 1998 ANOVA was not significant for the combined Manila and native littleneck CPUE. As noted above, native littlenecks comprise more than 95% of the total littleneck clam harvest on Birch Bay.

Appendix Table 13 shows the summary ANOVA results (by creel survey year) for butter clam CPUE. A total of 40 ANOVAs were performed on data from18 beaches. Tide strata were a significant factor in CPUE in ten of the 40 ANOVAs: P.T. Ship Canal East in year 2000, West Penn Cove and Long Point in 1999, and seven beaches in 1998: Birch Bay State Park, South Indian Island County Park, West Penn Cove, WINAS-Maylor Pt East, Fort Flagler State Park, Potlatch State Park, and Camano Island State Park. Examining those beaches with three years of survey data, there was no persistent tide effect across years at P.T. Ship Canal East, Birch Bay, South Indian Island, West Penn Cove, or Potlatch. However, West Penn Cove had significant tide effects on butter clam CPUE in two of the three survey years (1998 and 1999). Examining those beaches with two years of survey data, there was no persistent tide effect across years for butter clams at WINAS-Maylor Pt East, Fort Flagler, or Camano Island. Long Point was only surveyed sufficiently to compare tide effects in 1999, so nothing can be said about the persistence of tide effects there.

Appendix Table 14 shows the summary ANOVA results (by creel survey year) for Pacific oyster CPUE. A total of 34 ANOVAs were performed on data from 18 beaches. Tide strata were a significant factor in CPUE in only two of the 34 ANOVAs, both in 1998: Wolfe Property State Park and Kitsap Memorial State Park. Both these beaches were also surveyed in 1999 and 2000, and tide was not a significant effect in those years. Thus, there was no persistent tide effect on oyster CPUE at either Wolfe Property or Kitsap Memorial.

2) Analysis of Alternate Tide or Day Strata

Since the results of the above ANOVAs indicated that the former tide strata were not advantageous in estimating mean CPUE for currently managed species, we next searched for alternative tide strata that might prove more useful than the former strata. Figures 38 - 41 show graphs of daily CPUE versus tide height for Manila clams, native littlenecks, butter clams, and Pacific oysters on some important public beaches.

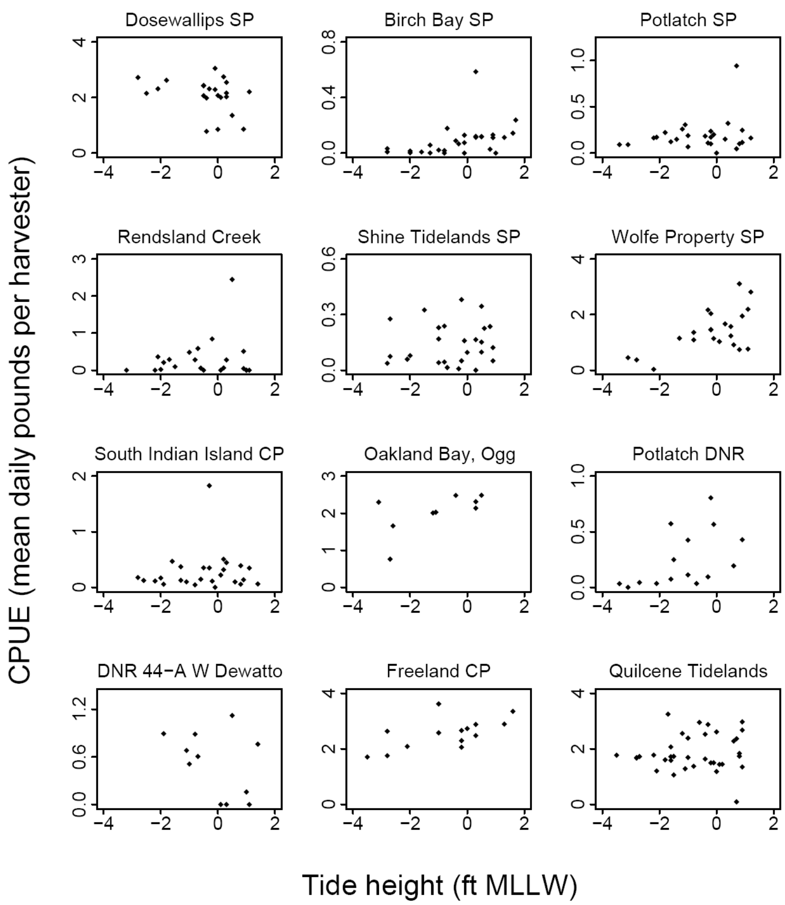

Figure 38. Daily CPUE ($CPUE_d$ in Equation 1) for Manila clams versus tide height at 12 public beaches.

Overall, there were no visibly obvious patterns with respect to tide height in the graphs for Manila clams, native littlenecks, or oysters. Oyster CPUE in particular appeared constant across all tide levels on most beaches. Butter clam CPUE exhibited an obvious tide effect on four of the nine important beaches illustrated (Camano Island State Park, West Penn Cove, WINAS-Maylor Pt East, and Birch Bay State Park). On these beaches, there was a fairly linear pattern of CPUE which was inversely related to tide height, at least when data from all three years were pooled. On the other five beaches, however, this pattern was not as obvious. Moreover, linear patterns such as those exhibited at Camano Island State Park, for example, do not lend themselves to stratification; regardless of where one makes a strata division, there will always be a large amount of variance *within groups*.

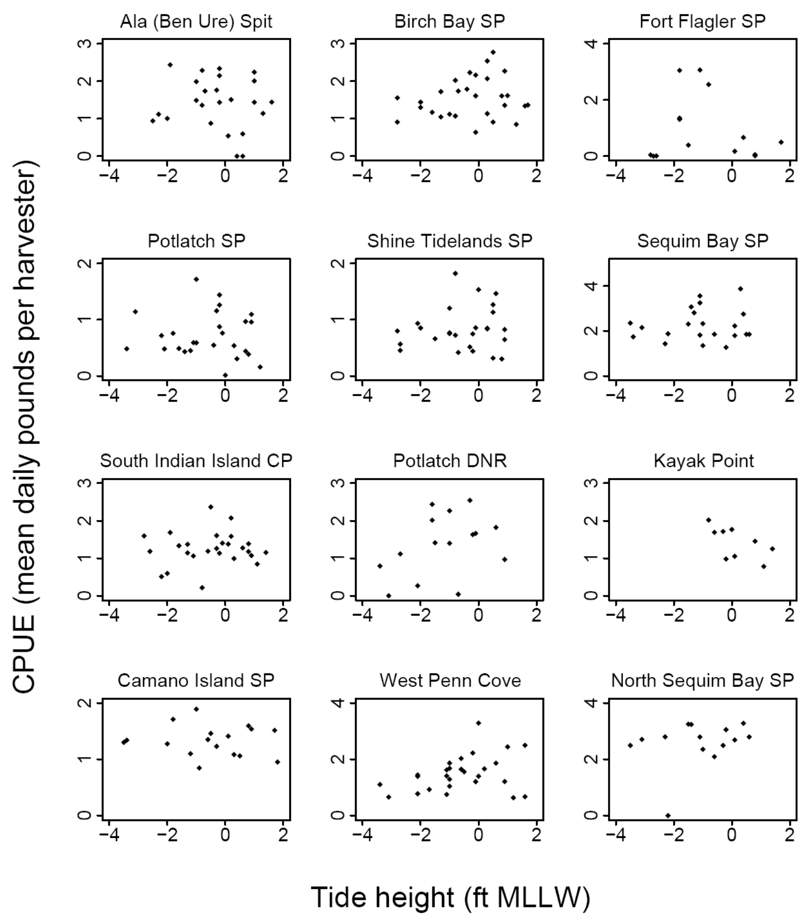

Figure 39. Daily CPUE (*$CPUE_d$* in Equation 1) for native littleneck clams versus tide height at 12 public beaches.

These graphs suggested that there was no obvious alternative tidal stratification that would be advantageous in estimating mean CPUE for Manila clams, native littlenecks, or Pacific oysters.

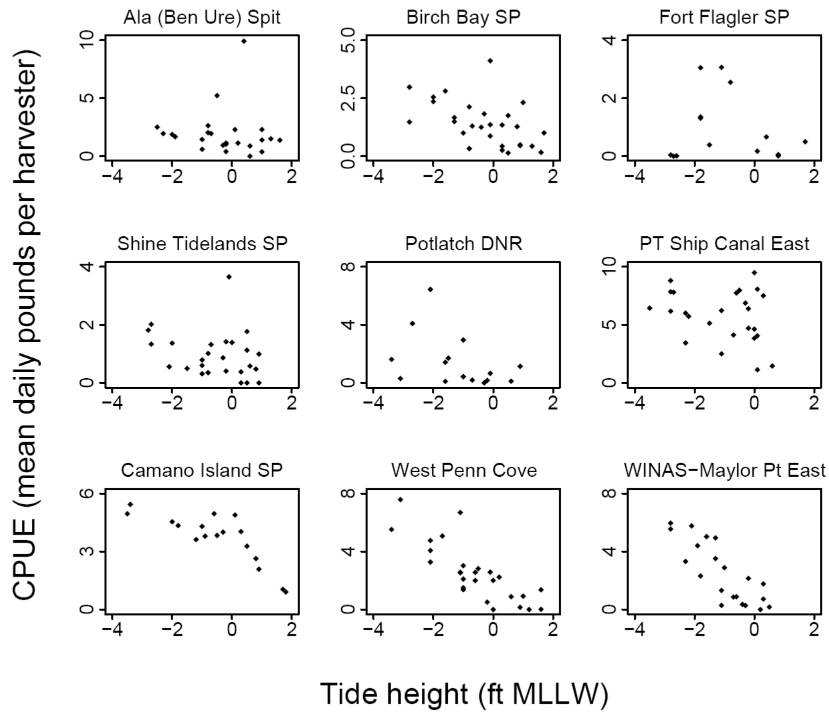

Figure 40. Daily CPUE ($CPUE_d$ in Equation 1) for butter clams versus tide height at nine public beaches.

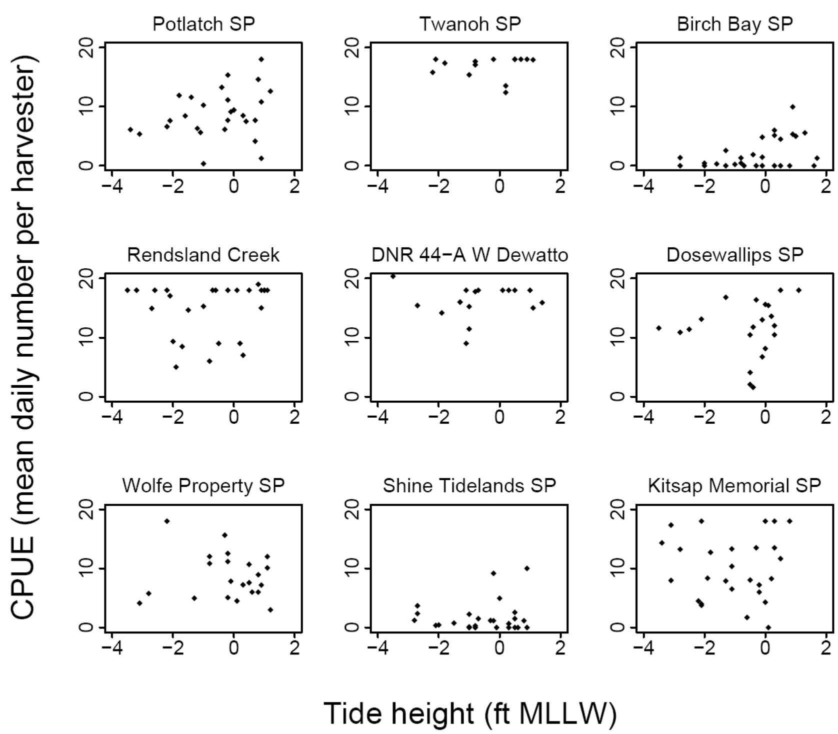

Figure 41. Daily CPUE ($CPUE_d$ in Equation 1) for Pacific oysters versus tide height at nine public beaches.

Alternate stratification schemes for butter clam mean CPUE estimates *may* be possible, but are likely to be advantageous on only a few beaches.

Appendix Table 15 shows the ANOVA results when testing the null hypothesis **H_0:** $\overline{CPUE}_{weekend} = \overline{CPUE}_{weekday}$ for important species on 21 beaches, using data from all creel surveys in 1998, 1999, and 2000. Day of the week was a significant factor for only one beach-species combination (butter clams on P.T. Ship Canal East).

Appendix Table 16 shows the ANOVA results when testing the null hypothesis that $\overline{CPUE}$ on weekend extreme low tides (ELOW) was equal to $\overline{CPUE}$ for the other tide-day strata combined. Only one beach (Manila clams on Oakland Bay Ogg) returned a significant test result, with CPUE significantly higher on "other strata combined" compared to weekend extreme lows.

The summary conclusion was that there were no advantages to stratifying $\overline{CPUE}$ by tide height, at least for species that are currently managed (Manila clams, native littlenecks, and Pacific oysters). Likewise, there were no significant advantages to introducing day-of-the-week strata into CPUE estimation.

3) Monte Carlo Simulation of Minimum Sample Size

Appendix Table 17 shows the actual sample size (number of creel surveys) and resulting relative standard error (RSE) of *unstratified* mean CPUE ($\overline{CPUE}$) for dominant clam species on 18 beaches sampled in year 2000. Clearly, the formerly recommended sample size of three creel surveys per tide stratum (i.e., a total of nine creel surveys) was rarely achieved in practice. Sample sizes in year 2000 ranged from four to 16, averaging about seven surveys. RSEs ranged from 0.05 to 0.27, averaging 0.15. Of the 18 beaches listed, only three had RSEs that exceeded our desired precision level of 0.20.

Figure 42 is based on the data from the 18 beaches in Appendix Table 17, and suggests that the precision of the $\overline{CPUE}$ estimate is not strongly correlated with sample size (panel A). Instead, a much stronger correlation exists between precision and the *species composition of clams in the creel.* As Figure 42 (panel B) shows, beaches where the dominant clam species made up at least 70% of all clams in the creel *always* had an RSE for the dominant species $\overline{CPUE}$ that was below the desired precision level of 0.20. The average number of creel surveys performed for this subset of beaches was 7.5 surveys. On three beaches where Manila clams made up virtually 100% of the clam creel (Dosewallips State Park, Quilcene Tidelands, and Oakland Bay Ogg), RSE for Manila clam $\overline{CPUE}$ was very low, ranging from 0.10 to 0.05. Conversely, beaches with more of a diverse mixture of clam species in the creel (e.g., Triton Cove Tidelands) tended to have higher RSEs for the dominant species $\overline{CPUE}$.

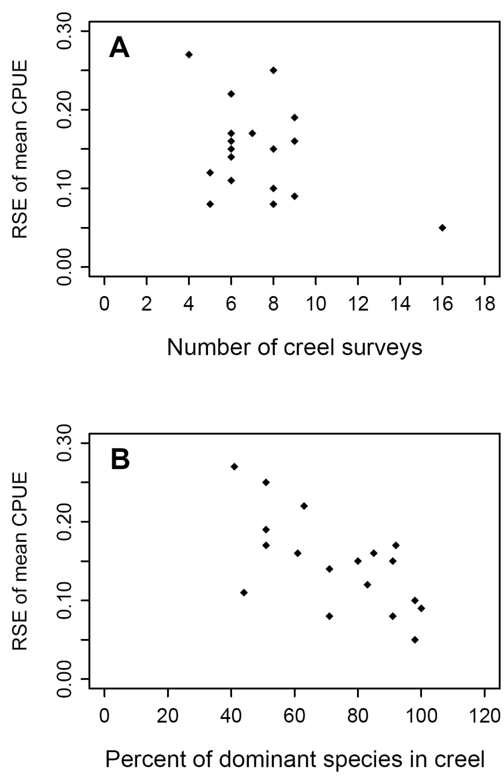

Figure 42. The effect of sample size (panel A) and species composition (panel B) on the Relative Standard Error (RSE) of mean CPUE at 18 public beaches. Mean CPUE estimates are for the dominant species in the creel at each beach. Data from Appendix Table 27.

Figure 43 shows graphs of the relative standard error (RSE) of $\overline{CPUE}$ versus sample size at ten important public beaches, based on the dominant species harvested at each beach. Similar graphs could have been made for all creel-surveyed beaches, but these examples were sufficient to provide some general guidance in selecting a sample size that achieved a prescribed level of precision. In the past, the recommended sample size (with tide stratification) was nine creel surveys per season.

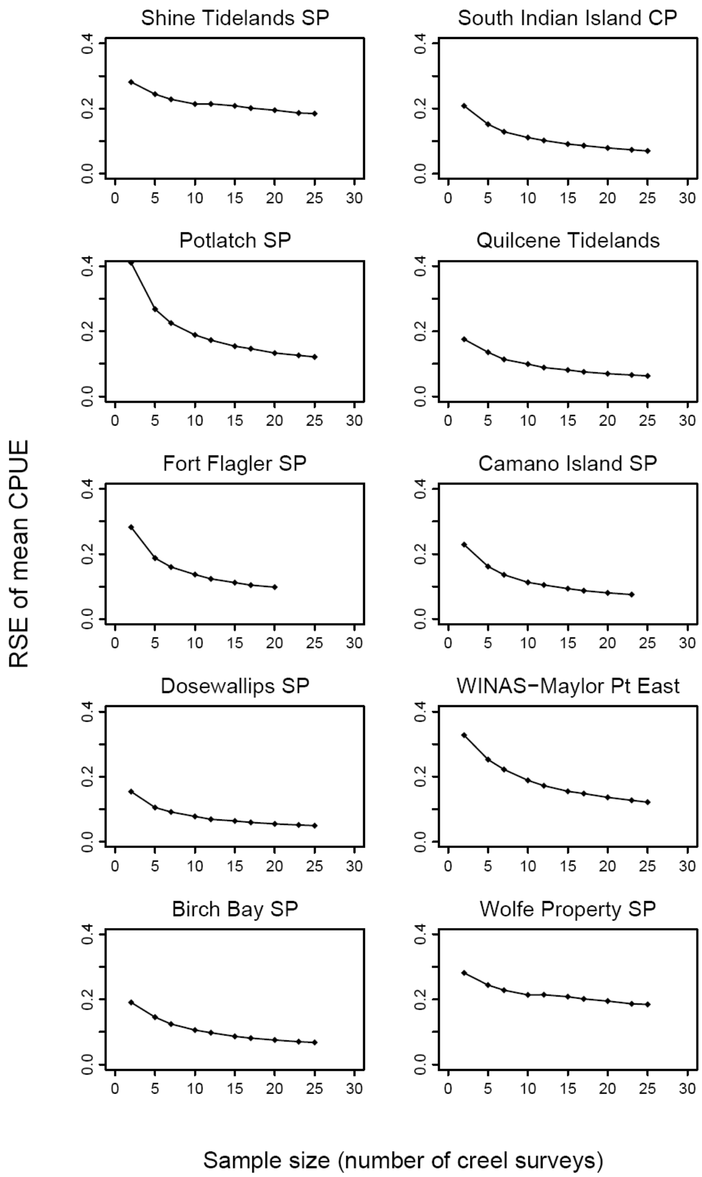

Figure 43. The Relative Standard Error (RSE) of mean CPUE versus sample size at ten public beaches, with the former tide strata (Extreme Low, Low and High) eliminated. CPUE pertains to native littlenecks at all beaches except Quilcene Tidelands, Dosewallips SP, and Wolfe Property SP, where CPUE pertains to Manila clams. Expected RSE shown is the mean RSE of 1,000 bootstrap replicates for sample size n. Bootstrap replicates were drawn from all daily CPUE estimates from 1998 through 2001.

Figure 43 suggests that with this sample size *and with the elimination of tide strata*, the RSE of $\overline{CPUE}$ for dominant species in the creel is expected to average about 0.13. Eliminating tide strata (while maintaining the former recommended sample size per beach) would obviously improve the precision of $\overline{CPUE}$. The average RSE for a sample size of three surveys per strata at these beaches was 0.23, roughly double the RSE for a sample size of nine unstratified surveys.

Figures 42 and 43 suggest that the optimum sample size for creel surveys is best recommended on a beach-by-beach basis. For example, data from Shine Tidelands State Park shown in Figure 43 indicated that, on average, we could expect to achieve an RSE of 0.20 or lower only with a sample size greater than n = 17, whereas we would expect to achieve RSEs less than 0.20 on beaches like Dosewallips State Park, Quilcene Tidelands, and Birch Bay State Park with samples sizes as low as five. As noted earlier, an important reason for the difference is that these beaches have creels composed of almost entirely one species rather than a mixture of species. It is important to note that Figure 43 provides *average expectations* for RSE versus sample size n , based on existing records of variance. Due to sampling variance alone, any *individual* value of $\overline{CPUE}$ with sample size n could result in an RSE which is higher or lower than this expected *average* RSE. For example, in year 2000 at Shine Tidelands, we achieved an RSE of 0.17 for native littleneck $\overline{CPUE}$ with only seven surveys (Appendix Table 17). But Figure 43, based on resampling all values of daily CPUE ($CPUE_d$) over four years of creel surveys at Shine, suggests that on average, we could only expect RSE values of around 0.23 when using a sample size of n = 7. Put another way, if we settled for a sample size of seven surveys at Shine Tidelands on a regular basis, we would expect to exceed the desired precision level of 0.20 in many years. Likewise, based on Figure 43 we would expect the RSE of native littleneck CPUE at Camano Island State Park with a sample size of five surveys to *average, over the long term,* about 0.16; but over the long term, the RSE would likely *exceed* 0.20 on roughly 26% of the survey-years (based on the results of the bootstrap resampling). Thus, in this case it may be prudent to select a somewhat larger sample size ($n > 5$), in order to reduce the probability of exceeding the desired RSE level.

4) Analysis of Variance (CPUE Differences by Year)

Appendix Table 18 shows the summary ANOVA results in which $\overline{CPUE}$ for Manila clams was tested for significant year effects at 20 different beaches. Year was a significant factor in CPUE in only two of the 20 beaches: Wolfe Property State Park and Quilcene Tidelands. Wolfe Property has experienced a serious siltation problem in recent years which has affected Manila clam populations and harvest opportunities.

Appendix Table 19 shows the summary ANOVA results in which $\overline{CPUE}$ for native littlenecks was tested for significant year effects at 28 different beaches. Year was a significant factor in native littleneck CPUE in only two of the 28 beaches: Camano Island State Park and Potlatch DNR.

Appendix Table 20 shows the summary ANOVA results in which $\overline{CPUE}$ for Pacific oysters was tested for significant year effects at 15 different beaches. Year was a significant factor in CPUE in only three of the 15 beaches: Sequim Bay State Park, Dosewallips State Park, and Pt. Whitney Tidelands.

These test results suggested that CPUE on a beach could be estimated as a running average of several years of creel survey data. This conclusion also suggested that missing a year or two of creel survey data does not significantly alter the estimate of CPUE, provided that pooled data from the beach in other years are used as a surrogate value during the “missing” year.

5) Summary of Catch Per Unit Effort Estimation Results

The first question we asked was: Were the former tide strata advantageous in estimating mean CPUE for clams and oysters? ANOVA tests on the 1998-2000 creel survey data indicated that the former stratification by tide height did not improve the precision of CPUE estimates for managed species. On the contrary, de-stratified estimates of CPUE were roughly twice as precise as tide-stratified estimates. Tide stratification in our case also failed to provide any of the other potential benefits of stratification mentioned for creel surveys: easier administration and greater information yield (Pollock et al. 1994).

The next question we asked was: Are there other tide strata or day-of-the-week strata that might provide more precise estimates of CPUE? Graphs of CPUE versus tide height failed to suggest any alternative tidal stratification that would be advantageous in estimating CPUE for managed species. Alternate stratification designs for butter clam CPUE may be possible, but are likely to be advantageous on only a few beaches. ANOVA tests on 21 beaches indicated that stratifying CPUE by weekend/weekday would not provide more precise estimates. Likewise, ANOVA tests failed to show any statistical advantage to stratifying CPUE with a separate stratum for weekend extreme low tides.

The third question we asked was: What is the optimum sample size (number of creel survey days) per beach to obtain a level of precision useful for management? We determined that CPUE estimates with a relative standard error (RSE) of roughly 0.20 would provide adequate precision for management. Monte Carlo simulations using the 1998-2001 creel survey data indicated that, on average, nine creel surveys per beach provided this level of precision or better for dominant species in the creel. However, the optimum sample size is best recommended on a beach-by-beach basis. This is because precision is strongly correlated with the species composition of clams in the creel. On beaches where the dominant clam species made up at least 70% of all clams in the creel, an average of 7-8 creel surveys always provided adequate precision for management purposes.

The last question we asked was: Does CPUE vary from year to year on a beach? ANOVA tests on the 1998-2001 creel survey data indicated that CPUE for managed clams and oysters did not vary significantly over the four-year period, except in a very few instances. This conclusion suggested that CPUE on a beach could be estimated as a running average of several years of creel survey data. This conclusion also suggested that missing a year or two of creel survey data would not significantly alter the estimate of CPUE, provided that pooled data from the beach in other years were used as a surrogate value during the "missing" year.

Glossary

Actively Managed Beach: As defined in current state-tribal Bivalve Management Plans, an actively managed beach is one where the demand for clams or oysters approximates the Total Allowable Catch (TAC), or is expected to approximate the TAC. Actively managed beaches include all beaches where commercial harvest by Tribes takes place, and include the most popular beaches for recreational shellfish harvest. Annual estimates of the recreational clam and oyster harvest are required on all actively managed beaches, unless otherwise agreed by state and tribal managers.

Activity Count: During an egress survey, an instantaneous count of all harvesters present on the beach at half-hour intervals. An activity count for a particular half-hour interval is divided by the total number of harvesters using the beach all day to produce an egress ratio for that half-hour interval.

All-day Effort: The total number of recreational clam/oyster harvesters using a particular beach during the course of a single day. All-day effort can be determined without error by directly counting all harvesters using the beach during an egress survey (generally six hours centered on the local low tide), or it can be estimated by expanding an instantaneous flight count of harvesters with an appropriate expansion factor from an egress model.

ANCOVA: Analysis of covariance.

ANOVA: Analysis of variance.

BIDN: Beach Identification Number. A unique six-digit number used to identify public beaches in Washington.

CI: Statistical confidence interval. In this report, all mention refers to 95% CIs.

Clam Beach: A beach where the predominant species harvested are clams (rather than oysters). Prior to 2007, we used a "clam beach" egress model to expand flight counts for all but three beaches designated as "oyster beaches" (Twanoh State Park, Lilliwaup State Park, and Seal Rock FSC).

clmuse: The SAS variable name for the expanded count of harvesters on a given beach on a given sample day. Equivalent to $\hat{E}_d$ in Equation 8. This number is the quotient of the observed instantaneous number of harvesters noted during the fly-over (E_t in Equation 8, equivalent to the SAS variable *uclam*) divided by the egress ratio ($\overline{R}_t$ in Equation 8).

CPUE: Catch per unit effort. As used in this report, CPUE for clams is the weight of clams taken per harvester-day; CPUE for oysters is the number of oysters per harvester-day.

CV: Coefficient of variation. As used in this report, the standard deviation of an estimated mean divided by the estimated mean itself.

Early Observation Group: A group of beaches in this study in which flight counts of recreational harvesters tend to occur 10-30 minutes prior to the time of local low tide.

Early Peak: A group of six public beaches identified in this study where the peak of all-day effort generally occurs about 30 minutes prior to the local low tide. These beaches were: Potlatch State Park, Potlatch DNR, Eagle Creek, Fort Flagler State Park, P.T. Ship Canal East, and Lilliwaup State Park. A separate egress model is used for these six beaches.

Effort Expansion Factor: See *Expansion Factor*.

Egress Correction Factor: A numerical factor used in this study to expand the total count of harvesters observed using a beach during the 4-hr ingress/egress surveys. Four-hr ingress/egress surveys were only conducted from 1998 to 2001. Analysis showed that 4-hr surveys significantly under-counted all-day effort when compared to 6-hr surveys. The correction factor used to expand the 4-hr survey counts in this study was 1.12648. Thus, if a total of 38 harvesters were counted during a 4-hr ingress/egress survey, the "corrected" count of all-day effort would be 38 x 1.12648 = 42.806 harvesters.

Egress Curve: For practical purposes, the same as an ingress curve. A graphical description of an egress model. The *x*-axis in such a graph represents the time intervals surrounding local low tide. The *y*-axis is the mean egress ratio (i.e., the expected proportion of all-day effort). In this report, egress curves are shown in Figures 3 and 37.

Egress Model: For practical purposes, the same as an ingress model. A mathematical model of the behavior of recreational clam and oyster harvesters on public beaches. An egress model relates the proportion of all-day harvester effort to the time of day (relative to local low tide), based on a series of egress surveys in which harvesters entering and using the beach are counted throughout a full day. Such models estimate all-day effort from an instantaneous count of harvesters made at a particular time in the tide cycle.

Egress Ratio: For practical purposes, the same as an ingress ratio. The proportion of all-day effort present on the beach at a particular time $\boldsymbol{t}$ (expressed as R_t). Egress ratios are estimated from egress/ingress surveys. The egress ratio for $\boldsymbol{t}$ = -60 minutes for a particular survey, for example, would be calculated by dividing the activity count at –60 minutes (the number of harvesters observed on the beach one hour before low tide) by the total number of harvesters observed using the beach during the entire egress/ingress survey. Egress ratios from a number of surveys are averaged for each time ***t*** to produce egress models. The mean egress ratio at time ***t*** is expressed as $\overline{R}_t$. The inverse of a mean egress ratio is called an expansion factor.

Egress Survey: For practical purposes, the same as an ingress survey. A survey during which all harvesters are counted as they leave ("egress") the beach; thus, a count of all harvesters using the beach during the course of the entire egress survey. Egress/ingress surveys provide counts of all-day effort from which to estimate ingress ratios for particular time intervals during a day.

ELOW: One of three tide-day strata used in stratifying effort surveys (the other two strata are LOW and HIGH). The ELOW stratum consists of weekend and holiday extreme low tides (i.e., tides –2.0 ft and lower).

Expansion Factor: In this report, the inverse of a mean egress ratio (i.e., $1/\overline{R}_t$). For example, if the mean egress ratio at time +30 minutes is 0.248, the corresponding expansion factor is 1 / 0.248 = 4.032. An expansion factor can be used to estimate the all-day effort from an instantaneous flight count of harvesters. In the example above, if 26 harvesters were counted at time +30 minutes, the estimated all-day effort would be 26 x 4.032 = 104.83 harvesters.

Extreme low tides: Tides –2.0 ft and below.

Flight Count: An instantaneous "head count" of recreational clam and oyster harvesters on a particular public beach, made from a fixed-wing aircraft. The flight count is equivalent to E_t in Equation 8. The flight route is structured such that most flight counts are made roughly within an hour of local low tide. The observer counts only recreational harvesters, and notes the exact time that the count on each public beach was made. Flight counts are expanded to estimate all-day effort on beaches using an appropriate expansion factor.

Harvester-Day: A unit of recreational effort equal to one visit (of any length of time) to a public beach by a sport harvester. Examples: If, during a 24-hr period from midnight to midnight on day *d*, 13 people visited Beach *x* to harvest clams and/or oysters, effort on Beach *x* on day *d* would equal 13 harvester-days. Similarly, if one harvester made 13 separate trips to Beach *y* during a calendar year, and no other harvesters visited Beach *y*, the annual effort on Beach *y* would equal 13 harvester-days. The period of time spent on the beach by a harvester (i.e., the length of a harvester-day) is immaterial for harvest-estimation purposes, since CPUE is estimated based entirely on interviews with harvesters who have completed their day's harvesting.

HIGH: One of three tide-day strata used in stratifying effort surveys (the other two strata are ELOW and LOW). The HIGH stratum consists of all high tides (i.e., tides 0.0 to 1.9 ft) and weekday low tides (i.e., tides –0.1 to –1.9 ft).

High Peak: A group of three public beaches identified in this study where the peak of all-day effort occurs roughly at the time of local low tide, but the peak proportion of all-day effort is significantly greater than at most other beaches. These beaches were: Dosewallips State Park, Duckabush, and Rendsland Creek.

High tides: Tides 0.0 to 1.9 ft.

Ingress Curve: See *Egress Curve*.

Ingress Model: See *Egress Model.*

Ingress Ratio: See *Egress Ratio.*

Ingress Survey: For practical purposes, the same as an egress survey. A survey during which all harvesters are counted as they enter ("ingress") the beach; thus, a count of all harvesters using the beach during the course of the entire ingress survey. Egress/ingress surveys provide counts of all-day effort from which to estimate ingress ratios for particular time intervals during a day.

LOW: One of three tide-day strata used in stratifying effort surveys (the other two strata are ELOW and HIGH). The LOW stratum consists of weekend low tides (i.e., tides –0.1 to –1.9 ft) and weekday extreme low tides (i.e., tides –2.0 ft and lower).

Low tides: Tides –0.1 to –1.9 ft.

Mean Egress Ratio: The average of several egress ratios (R_t) obtained during egress surveys, expressed for each time interval $\boldsymbol{t}$ as $\overline{R}_t$. Mean egress ratios are used to construct egress models.

MLLW: Mean lower low water. The arithmetic mean of the lower low water heights of a mixed tide observed over a specific 19-year Metonic cycle at a specific tidal reference station. Used to reference ambient tide heights to a standard tidal datum.

Normal Beaches: Public beaches identified in this study (other than Twanoh State Park) which did not fall into either the Early Peak group or the High Peak group, based on their pattern of daily effort. The peak effort on Normal beaches occurred roughly at the time of local low tide, but was significantly higher during weekend/holiday extreme low tides (the ELOW stratum) compared to the pattern during "non-ELOW" strata (the LOW and HIGH strata). Of the 140 beaches routinely flown in Bivalve Regions 1, 5, 6, 7 and 8 in 2005, 130 fell into the Normal beach category. Two egress models are currently used for Normal beaches: Normal, ELOW and Normal, non-ELOW.

Oyster Beach: A public beach where the principal species harvested is the Pacific oyster. Prior to 2007, we used an "oyster beach" egress model to expand flight counts for three public beaches designated as "oyster beaches" (Twanoh State Park, Lilliwaup State Park, and Seal Rock).

Passively Managed Beach: As defined in current state-tribal Bivalve Management Plans, a passively managed beach is one where the available information on state recreational and tribal ceremonial and subsistence harvest does not indicate the need for clam or oyster population surveys or a Total Allowable Catch (TAC). Only recreational and ceremonial and subsistence harvests are allowed on passively managed beaches. Annual estimates of recreational effort (but not catch) are made for most passively managed beaches.

Plus Tides: Tides ≥ 2.0 ft and < 4.0 ft.

Proportion Error: As used in this report, the 95% confidence bound on an estimate divided by the estimate itself.

Relative Standard Error (RSE): The standard error of an estimate (e.g., a mean egress ratio) divided by the estimate itself.

SAS: The computer software formerly used for the clam and oyster effort and catch estimation program.

Tide-day Strata: Three sampling strata (ELOW, LOW, and HIGH) currently used in stratifying effort surveys, based on combinations of tide height and days of the week with similar variance of daily effort. Use of these three strata has been shown to increase the statistical precision of effort estimates.

***uclam*:** The SAS variable name for the un-expanded instantaneous count of harvesters on a given beach on a given day. Equivalent to E_t in Equation 8. This instantaneous count is then expanded with an egress ratio (see Equation 8) and the resulting number is known as the SAS variable *clmuse* (see above).

WDFW: Washington Department of Fish and Wildlife.

WDFW Region 6: An administrative region within the Washington Department of Fish and Wildlife. For intertidal shellfish management purposes, WDFW Region 6 encompasses Bivalve Regions 1, 5, 6, 7 and 8.

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Appendix 1: Egress Metadata, Instructions, and Egress Forms Used From 1970 to 2005

Egress Metadata

Listed below is a brief description of all available ingress and egress data compiled in the historical archives at the Point Whitney Shellfish Lab. A number of problems were encountered when proofing these data, mostly related to use of incorrect low tide times in planning the surveys, and missing lines of data. Data deemed usable was systematically proofed using routines written in SAS code. Documentation of the process used to compile and verify data for each consecutive year is provided below. Examples of original data sheets are also included.

1970-72: Several surveys, five hours in duration, were conducted during the summers 1970-72 at beaches including Pt Whitney, Illahee, Fort Flagler and Eagle Creek. Surveys were collected on days when high numbers of harvesters were expected to be present. Because activity counts were not recorded separately, and the method of computing total ingress was not reported, these counts were not used.

1976: Several surveys were conducted at Pt Whitney in 1976. Some of these are potentially usable. Most were recorded on forms and indicate activity counts and ingress to both the beach and lagoon. Surveys ranged in length 2 ½ to 8 hours. Because these data were collected 30 years ago they may not be representative of present conditions and were not included in the analysis dataset. It would be worthwhile to revisit these data in the future to see how they compare with present ingress curves.

1980-82: Only a few surveys were available, mostly from Pt Whitney and Fort Flagler. Surveys were primarily 4 to 6 hours in duration and were conducted on busy days. The combination of high effort numbers and short surveys meant that many harvesters were missed on either end of survey. These surveys were consequently not included in the analysis dataset.

1988: Problems similar to 1980 were encountered. Only a few surveys were conducted and these spanned mostly 4 hour periods. The spans appeared to be inconsistent relative to the low tide. The data were not included in the final analysis dataset.

1989: Good data, well documented, with many surveys conducted. Surveys were 6 hours in duration and were complete in nearly all cases. There were no lines of missing data in the final dataset. The field survey sheet included a line for recording arrival counts. This facilitated accounting for harvesters already on the beach prior to the beginning of the survey. Each datasheet was individually proofed. The sum of the first activity count for clams and oysters was used as the initial ingress value. Several surveys needed to be manually entered, as they were not present in the electronic files. Specifics on proofing of the survey data are recorded in the program *IngressData89.sas*.

1990: Comparable to 1989 data. Surveys were 6 hours in duration. Data compiled in the original Allingress88-91 condor file dated 1991 served as the raw dataset. Specifics on proofing of the survey data are recorded in the program *IngressData90.sas*.

1991: Comparable to 1989 and 1990 data. Surveys were 6 hours in duration. There did not appear to be any missing datasheets when compared with the original entered data. Data compiled in the original Allingress88-91 condor file dated 1991 served as the raw dataset. Specifics on proofing of the survey data are recorded in the program *IngressData91.sas*.

1992: Comparable to 1989-91 data. Surveys were 6 hours in duration. Used INGRES92.db, originally compiled in Sept. of 1992 as the base dataset. Specifics on proofing of the survey data are recorded in the program *IngressData92.sas*.

1994: Only winter surveys were conducted in 1994. Data from 1994 were not incorporated into the final analysis dataset.

1995: Only winter surveys conducted in 1995. Data from 1995 were not incorporated into the final analysis dataset.

1996: Last year for 6 hour surveys. Previously entered data (ING96RAW.DB) was proofed using routines outlined in *IngressData96.sas*. Problems that were corrected are listed in the program.

1998: Surveys were truncated to 4 hours in duration beginning in 1999. Previously entered data (*Ingress98-00.mdb)* was proofed using routines documented in the *IngressData98-00.sas* program. The 1998 data was extracted. Problems that were corrected are outlined in *IngressData98-00Prg.sas*.

1999: Surveys were 4 hours in duration. Previously entered data (*Ingress98-00.mdb)* was proofed using routines outlined in *IngressData98-00.sas* program. The 1999 data was extracted. Ingress values for beach 250470 on 4/22/99 were changed because proportion effort exceeded 1.0 for one interval. The source of the problem was evident in the datasheet and the values were corrected. Other corrected problems are outlined in *IngressData98-00Prg.sas*.

2000: Surveys were 4 hours in duration. Previously entered data (*Ingress98-00.mdb)* was proofed using routines outlined in *IngressData98-00.sas* program. The 2000 data was extracted. Problems that were corrected are outlined in *IngressData98-00Prg.sas*.

2001: Surveys were 4 hours in duration. These data had not previously been entered. They were entered and subsequently proofed using routines in *IngressData01.sas*.

2004: Full six hour surveys were revived for 2004. Previously entered data (Ingress89-05) were proofed using routines outlined in *IngressData04.sas*. The 2004 data was extracted and proofed a second time. Problems that were corrected are outlined in *IngressData04.sas*.

2005: Surveys were 6 hours in duration. Previously entered data for 2005 was proofed using routines outlined in Ingress89-05.sas. The 2005 data was extracted and proofed a second time using the program *IngressData05.sas.* Problems that were corrected are outlined in *IngressData05.sas*.

AllEgress89-05: This file contains the complete set of Ingress data from all years with acceptable data. Individual years of data were combined and submitted to a final set of proofing routines using the program *AllData89-05.sas*. The database contains only data from WDFW Reg.6. If WDFW Reg. 4 data is needed for future analysis it must first be extracted from the base datasets residing in each annual folder. These must then be proofed using procedures similar to those documented in the individual proofing programs listed above.

Egress Forms and Instructions

(Egress Instructions 1970)

STATE OF WASHINGTON
DEPARTMENT OF FISHERIES
SHELLFISH LABORATORY
STAR ROUTE 2, BOX 120
BRINNON, WASHINGTON 98320

SPORT SHELLFISH SURVEY EVALUATION

1970 Ground Counts

Introduction

During the past two years Department of Fisheries personnel have made airplane flights over Puget Sound beaches to count the number of shellfish users. We now have enough past data to begin relating these instantaneous counts to the total number of people who use the shellfish resources of these beaches during a single tide. In order to do this we must know the number of people who enter and leave the fishery during set time intervals. The accompaning form has columns for those entering the fishery (#Ing.(I)), those leaving will be calculated (by us) from the difference between the total number and the entry (Ingress) information.

Instructions

1. Time of counting (time period).
   The observer will count 5 hours at half-hour intervals starting 3 hours before low water and ending 2 hours after low water. The time of each count will be entered on sheet under Time (24 hr).

2. Counting interval.
   A. Total number of people using clams and oysters on beach at each 30 minute interval to be entered under columns headed Tot. no. (N_1) on beach at ti using clams.

   B. Total number of people using crabs on beach at each 30 minute interval to be entered under columns headed Tot. no. (N_2) on beach at ti using crab.

   C. The number of people within defined area who commence taking shellfish (clams + oysters + crabs) to be entered in columns headed #Ing (I), totaled for each 30-minute period.

3. Beach users to be counted.
   A. Clam diggers and oyster pickers

   B. Crabbers

   C. Count the numbers of buckets and shovels only if it doesn't interfere with other counts.

4. Beach users to be excluded.
   Anyone not directly taking shellfish (children accompanying clammers, oyster pickers, or crabbers should be included).

5. Methods: The observer(s) must be so located that they have surveillence over all ingress on the beach plus being able to make the beach head counts every 30 minutes without losing touch of the ingress count.

6. Problems in making ingress counts.
   A. Separating out shellfish users from those not using shellfish.

   B. Determining if obvious shellfish users actually take shellfish from the defined areas.

   C. Partial solution:
      a. Observe those who have equipment for collecting or digging (i.e. shovels, buckets, rakes, crab forks, boots, rough clothes, etc.).

      b. Observe those who are obviously dressed for only swimming, sun bathing, or picnicing.

c. Observe those that stay above $\frac{1}{3}$ tide level.

7. Problems in making 30-minute head counts.
   A. Separating shellfish users from other beach-users.

   B. Boundaries: All counts of ingress and total shellfish users must be from defined areas only.

8. Please contact us after the first days counting if major problems develop (on keeping track of ingress, boundaries, etc.).

   Point Whitney Laboratory, Brinnon, Wa. - 796-4601
   Ron Westley, home phone, Quilcene, Wa. - 765-3568
   Al Scholz, home phone, Brinnon, Wa. - 796-4684
   Lynn Goodwin, home phone, Brinnon, Wa. - 796-4473

(Egress Form 1970)

DATA RECORD

Beach Census of Sport Shellfish Fishermen

(counts to be recorded at 30 min. intervals from 3 hrs. before low tide to 2 hrs. after low tide)

Date ____________
Location ____________
Time of Low Tide ____________
Hgt. of Low Tide ____________
Recorded By ____________
Checked By ____________
Weather ____________

Yr.	Mo.	Day	Location code
2	4	6	10

	Time period 12	Time (24 hr) 16	20	Counts from ti-30 to ti #Ing.(I) 24	#Shovels 28	#Buckets 32	Tot no (N_1) on beach at ti clam. 36	Tot no (N_2) on beach at ti crab. 40	44
	0								
	1								
	2								
	3								
	4								
	5								
Low water >	6								
	7								
	8								
	9								
	10								
	11								
	12								

Misc. Comments ____________

(Egress Instructions 1989)

PROCEDURES FOR INGRESS SURVEYS

PURPOSE: This sheet will give a surveyor general guidelines for the sucessful completion of ingress surveys.

REQUIRED EQUIPMENT:
A. Ingress Forms
B. Pencil
C. Tide Tables
D. Clipboard
E. Watch
F. If Necessary, Binoculars

FILLING OUT THE FORM: See completed form below

1. Fill in all blanks at the top of the form. Arrival counts should reflect the number of people harvesting on the beach at the time of arrival.
2. Circle the appropriate weather conditions on the day of survey.
3. Using the appropriate tide table, record the corrected low tide time next to time period six.
4. Record the time in half hour increments ascending from the low tide time.
5. Record the time in half hour increments decending from the low tide time.
   NOTE: Time period 0 should have a corresponding time of three hours before low tide. Similarly, time period 12 should have a corresponding time of three hours after low tide.
6. The start time will be the time corresponding to time period zero. Any harvesters ingressing between the time of arrival and time period 0 should be tallied under the column labeled Ingress Tally, time period zero. At time period zero, record under the appropriate column the total number harvesting clams, crabs, and oysters.
7. All ingressing harvesters between time period 0 and time period 1 should be tallied under Ingress Tally, time period one.
8. At time period 1 record totals and continue in the same manner until time period 12 has been reached.

NOTES:

1. Arrival time should generally be about 10 to 15 minutes prior to the start time(time period zero).

2. The comments section should be used to record anything out of the ordinary or other information believed to be of value.

3. The top of the form and time period increments should be calculated prior to arrival at the beach site.

4. To check for accuracy in any given time period add the tally for that time period to the total number harvesting in the previous time period. The number obtained should be equal or ~~less~~ more than the total harvesting in the time period being checked.

BEACH-USERS INGRESS CENSUS

B.I.D.N.: ____________ DATE: ____________
BEACH NAME: ____________ OBSERVER LOCATION ____________
OBSERVER ____________ ____________
ARRIVAL TIME ____________ OBSERVED AREA: ____________
HEIGHT OF TIDE: ____________ ____________
TIME OF TIDE: ____________ ____________

ARRIVAL COUNTS: CLAM DIGGERS: ________ CRABBERS: ________
OYSTER HARVESTERS: ________ OTHER: ________

WEATHER

TEMPERATURE			PRECIPITATION				WIND		
COOL	WARM	HOT	NONE	LIGHT	MED.	HVY	CALM	MED.	STRG

TIME PERIOD	TIME	INGRESS TALLY	TOTAL NUMBER CLAMMING	TOTAL NUMBER CRABBING	TOTAL NUMBER OYSTER HARVESTING
0					
1					
2					
3					
4					
5					
LOW TIDE 6					
7					
8					
9					
10					
11					
12					

COMMENTS: ____________

(Egress Form 1989)

Entered 8/25/89 MKM

Sport Shellfish Beach-Users Census

	Time Period	Time (24 hr.)	Ingress (No. of User)	Total No. on beach clamming	Total No. on Beach crabbing: Crabbing	Oys.
	0	Ø946	5	Ø	Ø	3
	1	1Ø16	9	Ø	Ø	13
	2	1Ø46	6	Ø	Ø	15
	3	1116	6	Ø	Ø	2Ø
	4	1146	18	Ø	Ø	25
	5	1216	42	4	Ø	55
LOW TIDE >	6	1246	17	11	Ø	42
	7	1316	10	9	Ø	13
	8	1346	5	Ø	Ø	8
	9	1416	11	1	Ø	12
	10	1446	2	1	Ø	9
	11	1516	Ø	Ø	Ø	Ø
	12	1546	Ø	Ø		Ø
			total 131			

Date: 22 APRIL 1989

Location: TWANOH SP 270460

Time of Low Tide: 12:46

Hgt. of Low Tide: -Ø.7

COMMENTS:

- TIME ARRIVED: 0828
- # OF CLAMMERS ON BEACH: Ø
- # OF OYSTER PICKERS: 4
- # OF CRABBERS: Ø

WEATHER: CLOUDY-COOL-OCCATIONAL RAIN

LOCATION OF SURVEY: E SIDE OF BOAT RAMP-CAN SEE FROM WEST BOUNDRY TO POINT.

Entered 8/25/ MKM

Sport Shellfish Beach-Users Census

	Time Period	Time (24 hr.)	Ingress (No. of User)	Total No. on beach clamming	Total No. on Beach crabbing: Crab	Oys.
	0	1019	4	Ø	Ø	7
	1	1049	8	Ø	Ø	12
	2	1119	25	2	Ø	26
	3	1149	24	5	Ø	3Ø
	4	1219	28	14	Ø	34
	5	1249	35	7	Ø	67
LOW TIDE >	6	1319	24	6	Ø	80
	7	1349	12	4	Ø	47
	8	1419	10	1	Ø	37
	9	1449	6	3	Ø	19
	10	1519	12	3	Ø	14
	11	1549	Ø	Ø	Ø	8
	12	1619	8	Ø	Ø	7
			total 196			

Date: 23 APRIL 89

Location: TWANOH SP 27046Ø

Time of Low Tide: 1319

Hgt. of Low Tide: -1.0

COMMENTS:

- TIME ARRIVED: 0941
- # OF CLAMMERS ON BEACH: Ø
- # OF OYSTER PICKERS: 3
- # OF CRABBERS: Ø

WEATHER: CALM-SUNNY

LOCATION OF SURVEY: E. SIDE OF BOAT LAUNCH-CAN SEE FROM WEST BOUNDRY TO POINT.

- INDIANS HARVESTING ON BEACH: 0941-1149

(Egress Form 1989)

SPORT SHELLFISH-USERS CENSUS

B.I.D.N. 270210

	TIME PERIOD	TIME (24 Hr.)	INGRESS (No. of Users)	TOTAL No. CLAMMING	TOTAL No. CRABBING	TOTAL No. HARVESTING OYS.
	0	0901	4	0	0	7
	1	0931	26	0	0 BY RAFT 2	32
	2	1001	38	0	WADING 2 BY RAFT 6	43
	3	1031	91	FOR GEODUCKS 76	WADING 6 BY RAFT 2	42
	4	1101	75	FOR GEODUCKS 128	WADING 4	53
	5	1131	38	FOR GEODUCK 170	WADING 8	35
LOW TIDE	6	1201	13	FOR GEODUCKS 148	SNORKLING 1 WADING 9	18
	7	1231	14	FOR GEODUCKS 62	WADING 6	17
	8	1301	16	3	WADING 3	28
	9	1331	22	0	0	29
	10	1401	12	0	0	15
	11	1431	6	0	0	6
	12	1501		0	0	0

BILL C.

B.I.D.N. 270210

DATE JUNE 4, 1989

BEACH NAME SEAL ROCK SP

WEATHER CLEAR + SUNNY / WARM VERY LIGHT WIND.

TIME OF LOW TIDE 1201

HGT. OF LOW TIDE -3.6

TIME OF ARRIVAL 0843

TIME OF ARRIVAL COUNTS:

CLAMMERS 0

CRABBERS 0

OYS. HARVESTERS 3

OTHER 0

4 SCUBA DIVERS HARVESTING SUBTIDALLY

OBSERVER LOCATION: APPROX 300 YARD FROM THE SOUTH. BOUNDARY BELOW THE STAIRS THE WHITE BOUNDARY POST IS IN SIGHT

COMMENTS: OBSERVED AREA; CAN SEE JUST AROUND FIRST POINT FROM SOUTH BOUNDARY TO THE SOUTH BOUNDARY. PARK RANGER SAYS IT IS HEAVIEST USED GROUND

(Egress Form 1989-1991)

BEACH-USERS INGRESS CENSUS

B.I.D.N.: 250400

DATE: 28 April 1991

BEACH NAME: Oak Bay West

OBSERVER LOCATION: near outhouses.

OBSERVER: JRS

ARRIVAL TIME: 0750

OBSERVED AREA: from rock jetty to beach in front of private homes

HEIGHT OF TIDE: -0.7

TIME OF TIDE: 1057c

ARRIVAL COUNTS: CLAM DIGGERS: 0 CRABBERS: 0

OYSTER HARVESTERS: 0 OTHER:

WEATHER:

TEMPERATURE			PRECIPITATION				WIND		
COOL	WARM	HOT	NONE	LIGHT	MED.	HVY	CALM	MED	STRG

	TIME PERIOD	TIME	INGRESS TALLY	TOTAL NUMBER CLAMMING	TOTAL NUMBER CRABBING	TOTAL NUMBER OYSTER HARVESTING	Total # on Beach
	0	✓ 0757	0	0	0	0	0
	1	✓ 0827	5 walking	0	0	0	5
	2	✓ 0857	0	0	0	0	0
	3	✓ 0927	卌 |||| 9	7	2	0	9
	4	✓ 0957	|| 2	7	2	0	9
	5	✓ 1027	卌 卌 | 11	13	2	0	18 (3Kids)
LOW TIDE	6	✓ 1057	0	7	0	0	10 (3Kids)
	7	✓ 1127	1	3	0	0	6 (3Kids)
	8	✓ 1157	0	2	0	0	5 (3Kids)
	9	✓ 1227	卌 5	4	0	0	5 (1Kid)
	10	✓ 1257	|| 2	6	0	0	7 (1Kid)
	11	✓ 1327	0	0	0	0	0
	12	1357	|| 2	0	0	0	0

COMMENTS: Used personal vehicle, Begins light raining at 1100 but stops about 12:00

(Egress Instruction 1993)

PROCEDURES FOR INGRESS SURVEYS

EQUIPMENT NEEDED:	1. Ingress form	4. Watch
	2. Pencil	5. Binoculars, optional
	3. Clipboard	6. Tally counter, optional

FILLING OUT THE FORM:

1. Fill in as much information at the top of the form as you can before leaving for the beach. Use Seattle or Port Townsend HEIGHT OF TIDE, but use LOCAL LOW TIDE TIME calculated from the tidal correction factor table. Fill in the TIME column, except arrival time, by putting local low tide time next to time period 6 and, working earlier and later in half-hour increments, fill in the rest of the column. Time period 0 should correspond to three hours before low tide; time period 12 should correspond to three hours after low tide. Arrive on the beach 10 to 15 minutes before time period 0. (You must be set up and ready to go three hours before low tide.)

2. Upon arrival at the beach, fill in ARRIVAL TIME and corresponding TOTAL OF ALL PEOPLE ON BEACH, and divide into the four harvest categories. Fill in OBSERVER LOCATION and OBSERVED AREA. Circle weather conditions.

3. Watch for any shellfish harvesters (people coming onto the beach to gather clams, oysters or crabs) between arrival time and time period 0. Mark them down in the HARVEST INGRESS TALLY column for time period 0 using tally marks as they go onto the beach. For this tally, count only the people who are harvesting shellfish. You may have to watch people a moment to find out if they will be harvesting shellfish.

4. At time period 0, mark the TOTAL OF ALL PEOPLE ON BEACH, including non-harvesters. Then divide that total into four categories by what activity the people are doing at the time of the count. The sum of the four columns should equal the "total of all people on beach" column.

5. Watch for shellfish harvesters arriving between time period 0 and time period 1. Mark them down in HARVESTER INGRESS TALLY for time period 1. At time period 1, count total people as in step 4. Continue the survey in this manner until time period 12 is completed. Do not include crabbers on a dock in the ingress survey, although you can note them separately.

***** If you see what appears to be a Fisheries plane, it is very important to make a flyover count at the time the plane is over the beach. Note the time, and total number of people on the beach (divided into the four harvest categories). If you are not sure it's a Fisheries plane, count anyway. Later, time of count can be used to determine if it was a Fisheries plane.**

6. Count children as harvesters and ingressers if they are helping harvest shellfish. If they are small infants who cannot walk, don't count them as harvesters or ingressers, but do note them. If you can distinguish tribal harvesters, mark a "T" next to their count.

7. Anything interesting or unusual, such as sudden weather change, pollution, die-offs or enforcement problems, should be recorded in the comments section.

EAW:REV.26AUG93:A:\WP51\INGFRMEX

(Egress Form 1992-1996)

BEACH USER'S INGRESS CENSUS

BIDN: 250400	DATE: 5, April '92
BEACH NAME: Oak Bay West	OBSERVER LOCATION: between boat ramp and
OBSERVER: JLW	toilets - walk to jetty for counts.
ARRIVAL TIME: 0935	OBSERVED AREA: dike bordering ship
SEATTLE/(PT) HEIGHT OF TIDE: -0.8	canal on North to where houses
LOCAL TIME OF TIDE: 1213 + 27 = 1240	begin on South end of beach plus entrance to lagoon

TEMPERATURE			PRECIPITATION				WIND		
COOL	WARM	HOT	NONE	LIGHT	MED	HVY	CALM	MED	STRG

~high 40's

I included oyster harvesters

Daylight time savings began today

TIME PERIOD	TIME	HARVESTER INGRESS TALLY*	TOTAL OF ALL PEOPLE ON BEACH#	NUMBER CLAMMING	NUMBER CRABBING	NUMBER OYSTER HARVESTING	NUMBER DOING OTHER
ARRIVAL TIME	0935		Ø	Ø	Ø	Ø	Ø
0	0940✓	Ø	Ø	Ø	Ø	Ø	Ø
1	1010✓	Ø	Ø	Ø	Ø	Ø	Ø
2	1040✓	卌 卌 II	12	11	Ø	1*	0
3	1110✓	卌	18	13	1	3*	1
4	1140✓	卌	22	19	Ø	2*	1
5	1210✓	卌	10	10	Ø	Ø	Ø
LOW TIDE 6	1240✓	卌	11	11	Ø	Ø	Ø
7	1310✓	卌 卌	17	14	Ø	3	Ø
8	1340✓	IIII	15	6	Ø	Ø	9 ← 3 of these people harvesting mussles
9	1410✓	Ø	6	4	Ø	Ø	2 ← harvesting mussles
10	1440✓	Ø	8	4	Ø	Ø	4 ← =6 plus 2 kids doing other in lagoon
11	1510✓	Ø	5	1	Ø	Ø	4
12	1540✓	Ø	Ø	Ø	Ø	Ø	Ø

* Yes, there are a few oysters on the jetty

EAW:18MAR92:A:\INGRFORM.WQ1

*TALLY OF HARVESTERS-ONLY WHO INGRESS BETWEEN TIME PERIODS.
#TOTAL NUMBER OF ALL PEOPLE ON THE BEACH AT TIME PERIOD.
(DIVIDE INTO FOUR TYPES; SUM OF FOUR TYPES SHOULD EQUAL THIS COLUMN)

COMMENTS: 0935 No campers in the campground - Hundreds (~300) of geese feeding at waters edge. They left when the first people arrived

See other side →

(Egress Form 1995-1996)

INGRESS SURVEY FORM

BIDN:	DATE:
BEACH NAME:	SURVEYOR:
SEATTLE HEIGHT OF TIDE:	SURVEYOR LOCATION:
LOCAL TIME OF TIDE:	SURVEYED AREA:
COMMENTS:	

TEMPERATURE			PRECIPITATION				WIND			
COOL	WARM	HOT	NONE	LIGHT	MED	HVY	CALM	LIGHT	MED	STRG

ARRIVAL COUNT:

		TIME		**COUNT ON THE HALF-HOUR**				
TALLY DURING INTERVAL		TIME PERIOD	TIME	TOTAL OF ALL PEOPLE ON BEACH	NUMBER CLAMMING	NUMBER CRABBING	NUMBER OYSTER HARVESTING	NUMBER DOING OTHER
HARVESTER INGRESS TALLY	**INTERVAL**	0						
	Between 0 and 1	1						
	Between 1 and 2	2						
	Between 2 and 3	3						
	Between 3 and 4	4						
	Between 4 and 5	5						
	Between 5 and 6	LOW TIDE 6						
	Between 6 and 7	7						
	Between 7 and 8	8						
	Between 8 and 9	9						
	Between 9 and 10	10						
	Between 10 and 11	11						
	Between 11 and 12	12						

EAW(30MAR95)>D:\FORMS\INGRFORM.WQ1

COMMENTS:

(Egress Instructions 1998)

1998 Region 4
How to compete the
Ingress/Egress Form

Purpose of the form

The Ingress/Egress Form is designed to collect data to improve the ingress ratio used in the calculation of effort. The ingress expansion factor effects the overall estimate of harvesting effort more than any other factor. The application of the ingress ratio on flight data expands the observed values (raw data) collected during aerial surveys. Currently, all observed effort is expanded by one ingress curve that was generated from data collected in 1991 and 1992. With the exception of an impromptu six week study during the end of 1996, no additional data has been collected to help refine the ingress estimate since its original application.

From this historic data it has been determined that while that while clam harvester ingress distribution curves are generally symmetrical, they vary greatly between years and between beaches. The sources of these differences are tide and daytype stratification and precipitation. For more information about the analysis of the historical data, please ask for a copy of the Ingress Analysis.

Who to sample

You need to count every clam or crab harvester as they enter and/or leave the beach in 10 minute intervals. Do not count those harvesting shore crabs, seaweed, shore snails (including moon snails), sand shrimp or mussels even if they remove these species.

What to do if you can't keep make a few counts

Incomplete I/E data is almost useless, so try to be as complete as possible. If you are unable to make a 10 minute interval count, write SKIP in the box. Be sure to conduct the ½ count within the assigned 10 minute interval. If you miss the 10 minute interval, do the count as soon as possible and write the time you did the count in the Actual Time column. Do the next 10 minute interval count at the pre-assigned time.

Should you miss any more than 4 consecutive 10 minute counts or two or more ½ hour counts, please make a note of the circumstances in the comments column. The purpose of this comment is not to reprimand you, but to help us determine if a separate I/E surveyor is required for this beach.

How to interview

Relax. Note the time of the local low tide at the 0:00 (low tide hour). In the Actual Time column, note the actual time of the 10 minute intervals. You might want to bring a timer or set your watch to signal every ten minutes.

Completing the form

1) BIDN: Beach identification number. Found on the schedule or on the selected 1998 beach list.
2) Beach Name: The name of the beach. Found on the schedule.
3) Seattle Tide Height: The height of the low tide using Seattle as a standard. Found in tide book, in the news paper or on the computer.
4) Local Tide Time: The time of the low tide corrected for the location. From the tide book with appropriate correction from the table, or from the computer. Use the 24 hour clock (military time).
5) Date: The date of the survey. Found on the schedule. Try the format "dd,mm,yy".
6) Creeler: List three initial for each surveyor.
7) Creel Location: Location from which observer is counting. Examples are: parking lot or boat ramp.
8) Observed Area: Describe the area observed. This should be the entire beach unless there is more than one observer or pair of observers. If there is more than one observer (or pair), describe which part of the beach each observer has agreed to cover. An example is: from the big rock to the end of the beach.
9) Weather: Repeat what you wrote on the field from. Circle the appropriate word which best describes the weather for the entire day. Include temperature, precipitation, wind and cloud cover.
10) Comments: List anything and everything. It is better to write it down and decide later if it is significant. Continue on the back as necessary.

11) Ingress Tally: Keep a tally of the shellfish harvesters as they enter the beach. You can use hatch marks, but write the total number and circle this number (this makes it easier for data entry). Place a "0" in the box if you saw no one, write "skip" if you missed a count. Don't leave any box empty.

Do not include people:

- harvesting seaweed exclusively.
- harvesting sand shrimp exclusively.
- harvesting mussel exclusively.
- People collecting shore snails exclusively.
- People removing shells, glass or rocks.
- Kids removing small crabs for torturing at home.
- People walking (w/o dogs), kite flying, running or anyone not harvesting.

12) <u>Egress Tally:</u> Keep a tally of the shellfish harvesters as they exit the beach. You will need to be sure to include unsuccessful harvesters as well as people who may have not kept any of their catch. This means you may need to talk to everyone who leaves the beach if you can't tell or weren't watching what they were doing. Again, can use hatch marks, but total the count and circle it. Place a "0" in the box if you saw no one, write "skip" if you missed a count. Don't leave any box empty.

13) <u>Half Hour Use Counts:</u> Count the number of people who are participating in each of the five (5) use categories. You can use hatch marks, but total the number and circle it. If people are crabbing or clamming and are taking a break during the few moments you are counting, tally them as participating. Count children who are accompanying clamming adults as clamming, unless they are obviously not contributing to the catch. Place a "0" in the box if you saw no one, write "skip" if you missed a count. Don't leave any box empty.

The following people should be counted as **HARVESTing OTHER**:

- harvesting sand shrimp exclusively,
- harvesting mussels exclusively.
- harvesting sea weed exclusively.
- harvesting shore snail (including moon snails).
- collecting and removing the shore crabs.

The following people should be counted as doing **OTHER**:

- digging holes without intent to harvest (yes, you'd have to ask them).
- walking, running (w/o dogs), kite flying, reading etc.

If you have any questions about including people in the tally or use counts, make a note in the comments section. Describe exactly what they were doing (ask them is you can't tell), and mark down the hours they were doing the activity. We are less concerned about people who are not taking Manila and native littlenecks, butter, or horse clams, cockles, Dungeness or red rock crab or oysters.

(Egress Instructions 1998-2001)

1999 INGRESS/EGRESS SURVEY FORM DESCRIPTIONS
AND PROCEDURES

1. Beach ID number.
2. Beach name.
3. Seattle tide height.
4. Local tide time, (record in military time).
5. Survey date.
6. Surveyor's initials.
7. Description of ingress survey location(s).
8. Description of area(s) ingressed/egressed.
9. Circle one weather condition for each: Temp., Precip., and Wind. Record cloud (%).
10. Plus and minus numbers are listed in half hour increments beginning two hours before low tide and ending two hours after low tide.
11. Record actual time (in military time) next to corresponding half hour increments, including "Low Tide" time at "0:00".
12. Beach user actives. Beginning at two hours before low tide (-2.00) count the number of people participating in each activity listed, ("Clamming", "Oystering", "Crabbing", "Harv. Other", and "Other" (doing other). Record number in the appropriate box. When a zero count is observed record a "0" in the appropriate box.
13. Total number of people on beach. Tally the number of people "Clamming", "Oystering", "Crabbing", "Harv Other" and "Other" and record number in "Total on Beach" box. For subsequent half hour counts repeat number "12" and number "13".
14. Harvester ingress tally. Beginning at two hours before low tide (-2.00) count the number of harvesters (people with shovels, buckets, oyster knives, small plastic containers, baggies etc...) ingressing beach. Working in ten minute increments, count each harvester ingressing beach by recording a tally mark next to the appropriate time increment. Example: harvesters who ingress beach between the -2.00 and -1:50 time increment are tallied next to the -1.50 time increment, harvesters who ingress between the -1:50 and -1:40 time increment are tallied next to the -1:40 time increment, harvesters who ingress between the -1:40 and - 1:30 time increment are tallied next to the -1:30 time increment etc... A beach user activities count is also taken at the (half hour) -1:30 time increment. Continue ingress tallies to end of survey (+2:00 time increment).
15. Harvester egress tally. Beginning at two hours before low tide (-2.00) count the number of harvesters as they are egressing the beach. Working in ten minute increments count each harvester egressing beach by recording a tally mark next to the appropriate time increment. Example: harvesters egressing beach between the -2.00 and the -1:50 time increment are tallied next to the -1:50 time increment, harvesters who egress between the - 1:50 and -1:40 time increment are tallied next to the -1:40 time increment, harvester who egress between the - 1:4.0 and -1:30 time increment are tallied next tol the -1:30 time increment etc... A beach user activities count is taken on the (half hour) time increments. Continue egress tallies to end of survey (+2:00 time increment). At the last time increment (+2.00) the total number of harvesters ingressed should equal total number of harvesters egressed.
16. Record comments pertaining to ingress survey.

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(Egress Form 1998-2001)

2001 INGRESS/EGRESS SURVEY FORM

BIDN 1	Date: 5	Temp	Cool	Warm	Hot	
Beach Name: 2	Observer(s): 6	9 Precip	None	Light	Medium	Heavy
Seattle Tide Height: 3	Observer Location: 7	Wind	Calm	Light	Medium	Strong
Local Tide Time: 4	Observed Area: 8	Cloud(%)				

11 Counts at -2:00 should be arrival counts — Do not fill in shaded areas — 1

Actual Time	10	Harvester Ingress 1 Tally	Harvester Egress 15 Tally	12 Number Clamming	Oystering	Crabbing	Harv. Other	Other	Total on Beach
	-2:00								
	-1:50								
	-1:40								
	-1:30								
	-1:20								
	-1:10								
	-1:00								
	- 0:50								
	- 0:40								
	- 0:30								
	- 0:20								
	- 0:10								
Low Tide	0:00								
	+ 0:10								
	+ 0:20								
	+ 0:30								
	+ 0:40								
	+ 0:50								
	+ 1:00								
	+ 1:10								
	+ 1:20								
	+ 1:30								
	+1:40								
	+ 1:50								
	+ 2:00								

Comments: 16

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(Egress Form Instructions 2004-2005)

2004 INGRESS/EGRESS SURVEY FORM DESCRIPTIONS AND PROCEDURES

1 Beach ID number

2 Beach name

3 Seattle tide height

4 Local tide time (record in military time)

5 Survey date (MM/DD/YY)

6 Surveyor's initials

7 Description of ingress surveyor location(s)

8 Description of area(s) observed (e.g. "entire beach" or "south end")

9 Week Day: day of the week (Monday, Tuesday etc)

10 Circle one weather condition for each: Temperature, Precipitation, and Wind. Record % cloud cover. Weather conditions should best describe the predominant weather pattern during the survey.

11 Plus and minus numbers are listed in half hour increments beginning 3 hours before low tide and end 3 hours after low tide.

12 Record actual time of each ½ hour activity count. Before beginning the ingress survey, write the corrected local low tide time in the box that says "Low Tide". Fill in the rest of the actual time blocks based on actual local low tide time, by subtracting or adding ½ hour increments.

13 Beach User Activity Counts. Beginning at 3 hours **BEFORE** low tide (-3:00) count the number of people participating in each activity listed: "Clamming", "Oystering", "Crabbing", "Harv. Other" and "Other" (doing other, such as dog-walkers). Record the number of people engaged in each activity in the appropriate box. When a zero count is observed, record a "0" in the appropriate box. Activity counts **MUST** be conducted at the time written in each ½ hour "actual time" box.

14 Total number of people on the beach. Compile the number of people "Clamming", "Oystering", "Crabbing", "Harv. Other" and "Other" in the "Total on Beach" box for each ½ hour increment

For subsequent ½ hour counts, repeat numbers 12 and 13 above

15 Harvester egress tally. Beginning at 3 hours before low tide, tally the number of harvesters as they are egressing the beach. Work in ½ hour increments as noted on the survey form.

> Example: Harvesters leaving **between** –3:00 hours and –2:30 hours should be recorded in the first "Harvester Egress Tally" box. Harvesters leaving **between** –2:30 and –2:00 hours should be recorded in the second "Harvester Egress Tally" box from the top. For further clarification, the time increments are noted inside each tally box. Tally marks should be recorded in groups of five:

16 Total of Egress Tally. Total and record the tally marks from each of the individual "Harvester Egress Tally" boxes. This number will reflect the total number of people that left the beach during the survey.

17 Record any comments pertinent to the ingress/egress survey.

(Egress Form 2004-2005)

INTERTIDAL INGRESS/EGRESS SURVEY FORM

							10		
BIDN:	1	Date:	5	Week Day: 9	Temp.	Cool	Warm	Hot	
Beach Name:	2	Observer(s):	6		Precip.	None	Light	Medium	Heavy
Seattle Tide Height:	3	Observer Location:	7		Wind	Calm	Light	Medium	Strong
Local Tide Time:	4	Observed Area:	8		Cloud (%)				

Egress Tally corresponds to departures between 1/2 hour counts

Activity Count at -3:00 is the staff arrival count

Actual Time	11	15 Harvester Egress Tally	13 Activity Count					14 Total on Beach
			Clamming	Oystering	Crabbing	Harv. Other	Other	
12	-3:00	Tally between -3:00 and -2:30						
	-2:30	Tally between -2:30 and -2:00						
	-2:00	Tally between -2:00 and -1:30						
	-1:30	Tally between -1:30 and -1:00						
	-1:00	Tally between -1:00 and -0:30						
	-0:30	Tally between -0:30 and 0:00						
Low Tide	0:00	Tally between 0:00 and +0:30						
	+0:30	Tally between +0:30 and +1:00						
	+1:00	Tally between +1:00 and +1:30						
	+1:30	Tally between +1:30 and +2:00						
	+2:00	Tally between +2:00 and +2:30						
	+2:30	Tally between +2:30 and +3:00						
	+3:00	FINAL ACTIVITY COUNT ONLY						
Total of Egress Tally		16						

Comments: 17

CAS> C:\Data\HarvestEstimation\Ingress\04.SurveyForm.xls Revised 4/19/04 CAS

Appendix Tables

Appendix Table 1. Optimal allocation of n = 30 samples between two tide-day strata (HIGH and LOW), based on effort data from 1994 – 2001. Samples were allocated using Equation 25.

		Optimal # samples per stratum		
BIDN	**Beach Name**	*n HIGH*	*n LOW*	*n*
250050	Sequim Bay SP	12.06	17.94	30
250055	North Sequim Bay SP	13.69	16.31	30
250260	Fort Flagler SP	13.68	16.32	30
250410	South Indian Island CP	13.58	16.42	30
250470	P.T. Ship Canal East	11.92	18.08	30
250510	Wolfe Property SP	16.67	13.33	30
250512	Shine Tidelands SP	16.36	13.64	30
270050	DNR 57-B Brown Pt	15.35	14.65	30
270170	Pt Whitney Tidelands	13.63	16.37	30
270200	Dosewallips SP	13.72	16.28	30
270210	Seal Rock FSC	12.71	17.29	30
270230	Kitsap Memorial SP	15.70	14.30	30
270300	Eagle Creek	18.55	11.45	30
270380	DNR 44-A W Dewatto	17.00	13.00	30
270410	Scenic Beach SP	17.29	12.71	30
270440	Potlatch SP	16.00	14.00	30
270442	Potlatch DNR	12.10	17.90	30
270460	Twanoh SP	18.09	11.91	30
270500	Quilcene Tidelands	16.05	13.95	30
281140	Frye Cove CP	18.09	11.91	30
Mean sample size per stratum (rounded)		**15**	**15**	30

Appendix Table 2. Optimal allocation of *n* = 30 samples between three tide-day strata (ELOW, HIGH and LOW), based on effort data from 1994 – 2001. Samples were allocated using Equation 25.

		Optimal # samples per stratum			
BIDN	**Beach Name**	*n ELOW*	*n HIGH*	*n LOW*	*n*
250050	Sequim Bay SP	4.32	15.67	10.00	30
250055	North Sequim Bay SP	4.21	15.98	9.82	30
250260	Fort Flagler SP	5.10	17.05	7.85	30
250410	South Indian Island CP	5.36	14.02	10.61	30
250470	P.T. Ship Canal East	3.29	17.81	8.91	30
250510	Wolfe Property SP	2.77	17.18	10.05	30
250512	Shine Tidelands SP	2.06	14.86	13.08	30
270050	DNR 57-B Brown Pt	3.93	17.49	8.58	30
270170	Pt Whitney Tidelands	4.28	14.66	11.06	30
270200	Dosewallips SP	3.65	14.98	11.37	30
270210	Seal Rock FSC	5.88	15.28	8.84	30
270230	Kitsap Memorial SP	3.76	17.63	8.61	30
270300	Eagle Creek	1.92	18.68	9.40	30
270380	DNR 44-A W Dewatto	2.82	17.98	9.20	30
270410	Scenic Beach SP	3.11	18.14	8.74	30
270440	Potlatch SP	2.84	16.81	10.35	30
270442	Potlatch DNR	5.04	14.47	10.50	30
270460	Twanoh SP	2.22	18.86	8.92	30
270500	Quilcene Tidelands	4.51	18.55	6.95	30
281140	Frye Cove CP	1.69	18.13	10.19	30
Mean sample size per stratum (rounded)		4	16	10	30

Appendix Table 3. Optimal allocation of *n* = 30 samples between four tide-day strata (ELOW, HIGH, LOW and MED) based on effort data from 1994 – 2001. Samples were allocated using Equation 25.

		Optimal # samples per stratum				
BIDN	**Beach Name**	*n ELOW*	*n HIGH*	*n LOW*	*n MED*	*n*
250050	Sequim Bay SP	4.80	6.73	11.81	6.65	30
250055	North Sequim Bay SP	4.69	5.16	10.85	9.30	30
250260	Fort Flagler SP	4.88	3.41	11.39	10.32	30
250410	South Indian Island CP	5.44	6.60	8.38	9.58	30
250470	P.T. Ship Canal East	6.04	3.51	11.96	8.48	30
250510	Wolfe Property SP	3.46	7.46	9.38	9.70	30
250512	Shine Tidelands SP	3.22	4.38	11.70	10.70	30
270050	DNR 57-B Brown Pt	4.54	4.31	9.89	11.27	30
270170	Pt Whitney Tidelands	4.62	4.94	11.92	8.52	30
270200	Dosewallips SP	3.95	4.83	12.31	8.91	30
270210	Seal Rock FSC	6.54	3.92	9.83	9.71	30
270230	Kitsap Memorial SP	4.44	3.42	10.17	11.98	30
270300	Eagle Creek	2.15	5.61	10.54	11.70	30
270380	DNR 44-A W Dewatto	2.94	7.54	9.58	9.93	30
270410	Scenic Beach SP	2.93	12.50	8.22	6.34	30
270440	Potlatch SP	3.01	7.12	10.95	8.93	30
270442	Potlatch DNR	5.03	7.62	10.47	6.89	30
270460	Twanoh SP	2.48	6.25	9.96	11.31	30
270500	Quilcene Tidelands	4.37	14.77	6.74	4.13	30
281140	Frye Cove CP	1.87	5.95	11.33	10.85	30
Mean sample size per stratum (rounded)		4	6	11	9	30

Appendix Table 4. Summary ANOVA results testing the effect of the former six tide-day strata on clam and oyster effort for combined years 1998 – 2001. Effort variable E_t was transformed prior to ANOVA with the Freeman-Tukey square root transformation (Freeman and Tukey 1950). ANOVA tests were conducted using the SAS General Linear Models (GLM) procedure for unbalanced designs. * = significant test at α = 0.05 level. ** = significant test at α = 0.01 level.

BIDN	Beach Name	*Mode/ (group) DF*	*Error DF*	*F-value*	*P > F*		*Tide strata compared (missing strata)*	*Shapiro-Wilk P < W*		*Levene's P > F*		*Brown-Forsythe P > F*	
200060	Birch Bav SP	5	106	18.6	< 0.0001	**	all	0.61402		0.0202	*	0.0233	*
240030	Camano Island SP	5	27	7.62	< 0.0001	**	all	0.22262		0.0442	*	0.5048	
240150	West Penn Cove	5	146	21.05	< 0.0001	**	all	< 0.00010	**	0.0735		0.0070	*
240160	Long Point	5	140	27.15	< 0.0001	**	all	< 0.00010	**	0.0007	**	< 0.0001	**
240260	Ala (Ben Ure) Spit	5	44	1.63	0.1710		all	0.00168	**	0.0781		0.2588	
240440	Freeland CP	5	138	15.8	< 0.0001	**	all	0.01281	*	< 0.0001	**	0.0007	**
240520	WINAS-Maylor	5	141	40.05	< 0.0001	**	all	0.00088	**	0.0085	**	0.0045	**
240580	Kayak Point CP	3	8	7.87	0.0090	**	(WDEL,WEEL)	0.73916		0.0117	*	0.0196	*
250050	Sequim Bay SP	5	39	7.42	< 0.0001	**	all	0.04010	*	0.0017	**	0.1206	
250055	North Sequim	5	44	8.21	< 0.0001	**	all	0.13021		0.1905		0.3734	
250260	Fort Flagler SP	5	62	26.59	< 0.0001	**	all	0.16722		0.0420	*	0.0266	*
250410	South Indian	5	86	18.26	< 0.0001	**	all	0.13735		0.0305	*	0.1526	
250470	P.T. Ship Canal	5	73	26.13	< 0.0001	**	all	0.00062	**	0.3676		0.3798	
250510	Wolfe Property	5	49	4.24	0.0028	**	all	0.66584		0.0005	**	0.0014	*
250512	Shine Tidelands	5	61	17.3	< 0.0001	**	all	0.00342	**	0.2666		0.1900	
260110	Double Bluffs SP	5	141	12.38	< 0.0001	**	all	< 0.00010	**	0.0865		0.0096	**
270050	DNR 57-B Brown	5	125	35.12	< 0.0001	**	all	0.00172	**	< 0.0001	**	0.0004	**
270170	Pt Whitney	5	73	4.14	0.0023	**	all	0.22899		0.0002	**	0.0004	**
270200	Dosewallips SP	5	103	23.62	< 0.0001	**	all	0.34230		0.5876		0.5419	
270210	Seal Rock FSC	5	131	8.72	< 0.0001	**	all	< 0.00010	**	0.0363	*	0.0067	**
270230	Kitsap Memorial	5	57	5.38	0.0004	**	all	0.46047		0.0038	**	0.0091	
270300	Eagle Creek	5	65	5.85	0.0002	**	all	0.16548		0.0429	*	0.2094	
270380	DNR44-A W	5	99	9.65	< 0.0001	**	all	0.00004	**	0.0093	**	0.0472	
270410	Scenic Beach SP	5	61	5.86	0.0002	**	all	0.00970	**	0.5032		0.3181	
270440	Potlatch SP	5	99	20.63	< 0.0001	**	all	0.01894	*	0.0334	*	0.0583	
270442	Potlatch DNR	5	91	21.93	< 0.0001	**	all	0.00751	**	< 0.0001	**	0.0003	**
270460	Twanoh SP	5	141	33.16	< 0.0001	**	all	0.25940		0.0183	*	0.0334	*
270480	Rendsland Creek	5	127	8.6	< 0.0001	**	all	< 0.00010	**	< 0.0001	**	< 0.0001	**
270500	Quilcene	5	126	15.5	< 0.0001	**	all	< 0.00010	**	0.0270	*	0.0384	*
281140	Frye Cove CP	4	26	1.3	0.2948		all	0.06843		0.0709		0.3012	

Appendix Table 5. Summary ANOVA results testing the effect of the former six tide-day strata using Welch's ANOVA. * = significant test at α = 0.05 level. ** = significant test at α = 0.10 level.

BIDN	Beach Name	*Model (group) DF*	*Error DF*	*F-value*	*P > F*		*Tide strata compared (missing strata)*
200060	Birch Bay SP	5	45	17.26	< 0.0001	**	all
240030	Camano Island SP	5	10	20.42	< 0.0001	**	all
240150	West Penn Cove	5	56	34.03	< 0.0001	**	all
240160	Long Point	5	55	33.40	< 0.0001	**	all
240260	Ala (Ben Ure) Spit	5	9	2.82	0.0872		all
240440	Freeland CP	5	56	17.61	< 0.0001	**	all
240520	WINAS-Maylor Pt East	5	58	48.27	< 0.0001	**	all
240580	Kayak Point CP	3	3	31.75	0.0104	*	(WDEL,WEEL)
250050	Sequim Bay SP	5	17	10.92	< 0.0001	**	all
250055	North Sequim Bay SP	5	18	7.54	0.0006	**	all
250260	Fort Flagler SP	5	26	28.32	< 0.0001	**	all
250410	South Indian Island CP	5	34	10.12	< 0.0001	**	all
250470	P.T. Ship Canal East	5	28	26.27	< 0.0001	**	all
250510	Wolfe Property SP	5	19	3.97	0.0128	*	all
250512	Shine Tidelands SP	5	11	35.47	< 0.0001	**	all
260110	Double Bluffs SP	5	58	25.56	< 0.0001	**	all
270050	DNR 57-B Brown Pt	5	52	30.49	< 0.0001	**	all
270170	Pt Whitney Tidelands	5	31	6.30	0.0004	**	all
270200	Dosewallips SP	5	41	21.57	< 0.0001	**	all
270210	Seal Rock FSC	5	55	8.06	< 0.0001	**	all
270230	Kitsap Memorial SP	5	25	5.61	0.0014	**	all
270300	Eagle Creek	5	20	8.58	0.0002	**	all
270380	DNR 44-A W Dewatto	5	40	6.17	0.0003	**	all
270410	Scenic Beach SP	5	23	3.66	0.0139	*	all
270440	Potlatch SP	5	41	20.52	< 0.0001	**	all
270442	Potlatch DNR	5	36	20.11	< 0.0001	**	all
270460	Twanoh SP	5	57	35.96	< 0.0001	**	all
270480	Rendsland Creek	5	50	5.68	0.0003	**	all
270500	Quilcene Tidelands	5	51	13.17	< 0.0001	**	all
281140	Frye Cove CP	4	8	3.27	0.0695		all

Appendix Table 6. Mean proportion error (the 95% CI on stratified sample mean effort $\overline{E_{t,st}}$ expressed as a proportion of the estimate itself) on 28 Puget Sound beaches. The four stratification designs tested are described in Table 5. Sample size *n* refers to the number of aerial surveys performed during a season. Values of proportion error for each beach and sample size are the means of 1,000 Monte Carlo simulations.

	Two strata				Three strata				Four strata				Six strata			
BIDN	***n* = 15**	***n* = 20**	***n* = 30**	***n* = 45**	***n* = 15**	***n* = 20**	***n* = 30**	***n* = 45**	***n* = 15**	***n* = 20**	***n* = 30**	***n* = 45**	***n* = 15**	***n* = 20**	***n* = 30**	***n* = 45**
200060	0.5382	0.4323	0.3291	0.2394	0.5685	0.4439	0.3310	0.2418	0.6240	0.4341	0.3227	0.2359	0.7120	0.4277	0.3265	0.2396
240030	0.7303	0.5878	0.4412	0.3345	0.7710	0.6079	0.4462	0.3300	1.0375	0.5443	0.3937	0.2912	0.8878	0.8062	0.4877	0.3134
240150	0.7212	0.5585	0.4145	0.3227	0.7260	0.5583	0.4084	0.3076	0.9508	0.5027	0.3564	0.2644	0.9205	0.5393	0.3750	0.2710
240160	0.7066	0.5738	0.4219	0.3059	0.7510	0.5866	0.4373	0.3132	0.8088	0.5446	0.3970	0.2748	0.9694	0.5656	0.3826	0.2641
240260	0.7671	0.6159	0.4572	0.3453	0.7744	0.6125	0.4522	0.3358	0.8593	0.5939	0.4385	0.3232	0.9085	0.6003	0.4698	0.3387
240440	0.6016	0.4948	0.3581	0.2580	0.6757	0.5269	0.3879	0.2797	0.6801	0.5176	0.3729	0.2610	0.7514	0.5049	0.3693	0.2587
240520	0.5932	0.4714	0.3587	0.2564	0.6271	0.4824	0.3602	0.2630	0.6612	0.4536	0.3291	0.2310	0.8385	0.4709	0.3360	0.2267
250050	0.6441	0.5250	0.3904	0.2709	0.6202	0.4981	0.3665	0.2595	0.6477	0.4975	0.3624	0.2541	0.7364	0.4677	0.3230	0.2129
250055	0.7201	0.5817	0.4366	0.3096	0.7103	0.5573	0.4192	0.2983	0.7845	0.5323	0.3950	0.2769	0.8839	0.5545	0.4027	0.2809
250260	0.6065	0.4978	0.3703	0.2641	0.5693	0.4579	0.3324	0.2420	0.6663	0.4270	0.3029	0.2113	0.8374	0.4555	0.3043	0.2050
250410	0.5807	0.4718	0.3539	0.2446	0.5175	0.4038	0.2997	0.2104	0.5739	0.3975	0.2958	0.2075	0.6370	0.4184	0.3180	0.2286
250470	0.5838	0.4903	0.3545	0.2413	0.5022	0.4052	0.2935	0.2035	0.4956	0.3771	0.2691	0.1721	0.5345	0.3914	0.2566	0.1567
250510	0.5612	0.4364	0.3331	0.2434	0.5595	0.4307	0.3207	0.2337	0.6112	0.4268	0.3164	0.2314	0.5795	0.4142	0.3236	0.2352
250512	0.4800	0.3856	0.2951	0.2142	0.4769	0.3744	0.2766	0.2053	0.5191	0.3325	0.2420	0.1751	0.5402	0.3420	0.2526	0.1809
260110	0.6838	0.5496	0.4148	0.2985	0.7600	0.5920	0.4393	0.3193	0.7617	0.5759	0.4111	0.2873	0.7584	0.5647	0.3912	0.2644
270050	0.6481	0.5200	0.3929	0.2838	0.6407	0.4862	0.3646	0.2631	0.6841	0.4525	0.3313	0.2310	0.8629	0.4810	0.3465	0.2438
270170	0.8228	0.6647	0.4981	0.3608	0.8394	0.6566	0.4861	0.3502	0.9090	0.6678	0.4937	0.3479	0.9643	0.6696	0.4836	0.3364
270200	0.5644	0.4557	0.3399	0.2431	0.5667	0.4467	0.3278	0.2376	0.5704	0.4206	0.3059	0.2157	0.6463	0.4289	0.3119	0.2182
270210	0.8423	0.6631	0.4854	0.3447	0.7450	0.5898	0.4289	0.2978	0.8116	0.5559	0.4056	0.2708	0.7927	0.5934	0.4162	0.2858
270230	0.8685	0.7038	0.5300	0.3855	0.8728	0.6917	0.5090	0.3704	1.0225	0.6604	0.4965	0.3598	1.3371	0.7283	0.5556	0.4035
270300	0.6668	0.5376	0.4047	0.3000	0.6898	0.5426	0.4004	0.3004	0.8073	0.5156	0.3808	0.2789	0.8350	0.5491	0.4036	0.2981
270380	0.8733	0.6968	0.5264	0.3919	0.9166	0.7125	0.5305	0.3917	1.0522	0.7327	0.5436	0.4009	1.0111	0.7580	0.5924	0.4532
270410	0.8674	0.7171	0.5450	0.3988	0.8997	0.7229	0.5289	0.3918	1.1660	0.9655	0.6744	0.4896	1.5125	1.0026	0.9178	0.6571
270440	0.4777	0.3826	0.2882	0.2109	0.4846	0.3750	0.2774	0.2043	0.5031	0.3569	0.2653	0.1943	0.5438	0.3489	0.2522	0.1751
270442	0.8345	0.6942	0.5001	0.3463	0.7582	0.6162	0.4485	0.3078	0.7985	0.6480	0.4735	0.3170	0.7489	0.5849	0.3989	0.2505
270460	0.5196	0.4186	0.3129	0.2321	0.5243	0.4196	0.3041	0.2265	0.5967	0.3917	0.2946	0.2139	0.5553	0.3944	0.2938	0.2122
270500	1.0024	0.8301	0.6134	0.4643	1.0062	0.8305	0.5824	0.4325	1.3312	0.9250	0.6729	0.5019	1.4554	0.8500	0.7356	0.5459
281140	0.7806	0.6161	0.4697	0.3502	0.8094	0.6290	0.4612	0.3400	0.9188	0.5978	0.4379	0.3240	1.1201	0.6349	0.4505	0.3223
Mean	0.6888	0.5562	0.4156	0.3022	0.6915	0.5449	0.4007	0.2913	0.7805	0.5374	0.3922	0.2801	0.8529	0.5553	0.4099	0.2885

Appendix Table 7. Summary ANOVA results testing effect of the former month-group strata (the former "high-use" and "low-use" months) on effort counts (E_t) on 27 Puget Sound public beaches. Separate ANOVAs were performed for each year 1994-2001 and within each of two tide-day strata (LOW and HIGH). Sample size *n* refers to the number of aerial surveys performed. Shading highlights P-values that were significant at the α = 0.10 level. Asterisks in the comments column indicate cases where the mean effort in "low-use" months was greater than the mean effort in "high-use" months.

BIDN	Beach Name	YEAR	*P > F* (LOW)	*n*	*P > F* (HIGH)	*n*	Comments
200060	Birch Bay SP	2001	NA*	11	0.0903	16	
		2000	0.8932	11	0.7715	16	
		1999	0.4328	8	0.4848	16	
		1998	0.8590	14	0.7079	27	
		1997	0.2855	14	0.7551	25	
		1996	0.9595	14	0.3212	22	
		1995	0.2462	17	0.1553	18	
		1994	0.4531	16	0.6145	18	
240150	West Penn Cove	2001	0.4833	11	0.5855	23	
		2000	0.6791	13	0.1915	25	
		1999	0.9008	16	0.5962	20	
		1998	0.8768	19	0.0501	30	
		1997	0.9233	13	0.4938	25	
		1996	0.4113	14	0.3855	23	
		1995	0.3127	17	0.7138	17	
		1994	0.9807	17	0.8073	16	
240160	Long Point	2001	0.3829	11	0.1441	20	
		2000	0.1372	14	0.4123	24	
		1999	0.8276	16	0.0802	22	
		1998	0.3086	17	0.5623	24	
		1997	NA***	0	NA****	3	
		1996	NA**	1	NA****	4	
		1995	0.8736	16	0.1427	15	
		1994	0.3557	15	0.2806	12	
240260	Ala (Ben Ure) Spit	2001	0.5602	5	0.2898	10	
		2000	0.0514	5	0.3702	12	
		1999	NA****	2	NA****	9	
		1998	0.9498	7	0.3519	18	
		1997	NA***	0	NA****	4	
		1996	0.9755	4	0.8314	7	
		1995	0.6176	16	0.3664	19	
		1994	0.3986	15	0.6530	11	
240440	Freeland CP	2001	0.7588	11	0.8797	21	
		2000	0.4149	14	0.2369	25	
		1999	1.0000	17	0.1799	23	
		1998	0.6618	16	0.6208	23	
		1997	0.4156	12	0.9461	19	
		1996	0.3656	13	0.1750	13	
		1995	0.4204	16	0.8456	15	
		1994	0.1509	15	0.7242	13	
240520	WINAS-Maylor Pt East	2001	0.5638	11	1.0000	21	
		2000	0.1142	13	0.3711	25	
		1999	0.4547	16	0.0200	21	
		1998	0.1649	17	0.0910	29	
		1997	NA***	0	NA****	4	
		1996	0.0581	10	0.9102	18	
		1995	0.2033	10	0.3458	13	
		1994	0.5903	17	0.4387	18	
250050	Sequim Bay SP	2001	NA*	3	NA*	5	
		2000	NA*	8	NA*	10	
		1999	NA*	5	NA*	6	
		1998	0.9213	7	0.0727	12	
		1997	0.8556	6	0.1686	14	

		1996	0.4887	11	0.5332	18	
		1995	0.8410	12	0.4177	13	
		1994	0.2434	15	0.1129	19	
250055	**North Sequim Bay SP**	2001	NA*	3	NA*	5	
		2000	NA*	8	NA*	9	
		1999	NA*	3	NA*	3	
		1998	0.4412	7	0.3826	12	
		1997	0.4686	6	0.3744	13	
		1996	0.9137	11	0.7760	16	
		1995	0.6403	12	0.6462	13	
		1994	0.6520	15	0.5897	19	
250260	**Fort Flagler SP**	2001	0.2694	8	0.5114	11	
		2000	0.9436	9	0.6033	10	
		1999	NA**	1	NA****	5	
		1998	0.0062	10	0.8375	13	*
		1997	0.1226	11	0.3310	14	
		1996	0.1869	8	0.3856	13	
		1995	0.1384	12	0.7457	12	
		1994	0.7090	12	0.4926	12	
250410	**South Indian Island CP**	2001	0.1586	13	0.7275	16	
		2000	NA****	2	NA****	7	
		1999	0.0109	8	0.3523	16	*
		1998	0.9262	16	0.7610	26	
		1997	0.1541	11	0.2311	27	
		1996	0.7606	11	0.5510	19	
		1995	0.2464	15	0.1737	12	
		1994	0.0704	16	0.2738	21	
250470	**P.T. Ship Canal East**	2001	0.5823	3	0.1630	8	
		2000	1.0000	8	0.4463	12	
		1999	0.7239	9	0.9864	13	
		1998	0.1216	14	0.8280	21	
		1997	0.4544	3	0.5024	9	
		1996	0.4622	5	0.4952	7	
		1995	NA****	3	NA****	5	
		1994	0.5823	3	0.4071	9	
250510	**Wolfe Property SP**	2001	NA*	2	0.7160	11	
		2000	0.4995	7	0.0592	16	*
		1999	NA****	2	NA****	9	
		1998	NA****	2	0.5284	12	
		1997	0.0529	5	0.4924	16	
		1996	0.1254	12	0.5843	21	
		1995	0.2091	19	0.6111	18	
		1994	0.6365	5	0.8017	12	
250512	**Shine Tidelands SP**	2001	NA*	2	0.6723	7	
		2000	NA****	2	NA****	6	
		1999	0.0508	5	0.8920	11	
		1998	0.3140	17	0.5641	27	
		1997	0.7072	13	0.5580	26	
		1996	0.2748	10	0.4424	16	
		1995	0.6774	14	0.7894	15	
		1994	0.5459	17	0.4955	19	
260110	**Double Bluffs SP**	2001	0.4472	14	0.3404	20	
		2000	0.2675	13	0.9610	25	
		1999	0.1478	16	0.8749	26	
		1998	0.6218	15	0.8004	23	
		1997	0.1780	12	0.8865	19	
		1996	0.7195	15	0.3723	21	
		1995	0.7446	16	0.9570	17	
		1994	0.1021	18	0.5701	17	
270050	**DNR 57-B Brown Point**	2001	NA*	11	0.6382	16	
		2000	0.5780	8	0.2072	12	
		1999	0.0732	13	0.1833	22	
		1998	0.7143	16	0.7531	28	
		1997	0.4632	12	0.8907	19	

		1996	0.8550	9	0.5611	6	
		1995	0.1266	15	0.9018	13	
		1994	0.1836	16	0.2625	12	
270170	**Pt Whitney Tidelands**	2001	NA*	10	NA*	10	
		2000	NA*	2	NA*	3	
		1999	NA***	0	NA***	0	
		1998	NA*	10	NA*	12	
		1997	0.4275	13	0.1090	23	
		1996	0.8695	14	0.0692	23	
		1995	NA****	3	NA****	7	
		1994	0.9646	8	NA*****	10	
270200	**Dosewallips SP**	2001	0.0612	6	0.8982	7	*
		2000	0.6619	5	0.3307	11	
		1999	0.1310	11	0.0735	26	*
		1998	0.2309	15	0.4630	26	
		1997	0.2485	15	0.7546	31	
		1996	0.1124	13	0.9460	18	
		1995	0.1161	25	0.5385	38	
		1994	0.3150	24	0.2560	40	
270210	**Seal Rock FSC**	2001	0.1072	14	0.3729	26	
		2000	0.4737	12	0.3237	21	
		1999	0.6997	13	0.1000	25	
		1998	0.3460	13	0.0455	17	
		1997	0.1673	11	0.5025	24	
		1996	0.9626	15	0.5398	15	
		1995	0.4569	17	0.2887	18	
		1994	0.6599	15	0.5696	13	
270230	**Kitsap Memorial SP**	2001	0.6065	6	NA*****	5	
		2000	NA*	2	NA*	5	
		1999	NA*	4	NA*	8	
		1998	NA*	9	NA*	9	
		1997	0.2147	9	0.2938	18	
		1996	NA*	3	NA*	4	
		1995	NA****	4	NA****	4	
		1994	0.3520	12	0.0524	9	*
270300	**Eagle Creek**	2001	NA*	3	NA*	5	
		2000	NA*	4	NA*	4	
		1999	NA***	0	NA***	0	
		1998	0.2470	13	0.4687	21	
		1997	0.8133	10	0.0086	19	
		1996	0.2352	15	0.2046	14	
		1995	0.4786	18	0.1660	11	
		1994	0.7753	12	0.2013	11	
270380	**DNR 44-A W Dewatto**	2001	0.2562	9	0.4048	12	
		2000	0.1206	12	0.3107	18	
		1999	NA***	0	NA***	0	
		1998	0.3352	13	0.8675	13	
		1997	0.3477	8	0.3499	15	
		1996	0.1242	16	0.5029	22	
		1995	0.2646	10	0.0617	14	*
		1994	0.8432	9	0.7935	14	
270410	**Scenic Beach SP**	2001	NA*	7	0.5336	9	
		2000	0.3427	6	0.6039	8	
		1999	0.8198	6	NA*	8	
		1998	0.6934	7	0.2175	9	
		1997	0.4676	6	0.5415	6	
		1996	0.3845	13	0.9613	13	
		1995	0.5827	14	0.6867	14	
		1994	0.2972	16	0.1904	14	
270440	**Potlatch SP**	2001	NA*	10	0.9927	15	
		2000	0.6273	9	0.3173	14	
		1999	0.4057	5	0.8401	14	
		1998	0.5919	17	0.5558	24	
		1997	0.9282	11	0.6250	21	

		1996	0.2300	9	0.1837	13	
		1995	0.2159	5	0.3178	11	
		1994	0.8443	10	0.2787	11	
270442	**Potlatch DNR**	2001	NA*	9	0.5018	13	
		2000	0.6427	10	0.3300	14	
		1999	0.5458	5	0.4153	10	
		1998	0.7516	15	0.0774	22	*
		1997	0.2336	11	0.0882	23	
		1996	NA***	0	NA***	0	
		1995	NA***	0	NA***	0	
		1994	0.2608	18	0.8868	21	
270460	**Twanoh SP**	2001	0.2974	14	0.4823	22	
		2000	0.9841	13	0.8905	21	
		1999	0.6658	13	0.7020	24	
		1998	0.4639	15	0.9067	27	
		1997	0.6488	13	0.4804	23	
		1996	0.2891	13	0.4400	17	
		1995	0.7340	18	0.5181	18	
		1994	0.1161	15	0.6953	18	
270500	**Ouilcene Tidelands**	2001	0.7212	15	0.2958	24	
		2000	0.8625	12	0.6015	19	
		1999	0.1850	14	0.2912	22	
		1998	0.1111	19	0.5102	32	
		1997	0.9092	7	0.2290	15	
		1996	0.7766	22	0.4230	16	
		1995	0.0987	12	0.0409	19	
		1994	NA***	0	NA***	0	
281140	**Frve Cove CP**	2001	NA*	4	0.2070	8	
		2000	0.5069	5	0.7857	12	
		1999	NA**	1	NA****	3	
		1998	NA***	0	NA****	3	
		1997	0.2809	3	0.4785	9	
		1996	0.2716	14	0.4937	22	
		1995	0.9398	19	0.7222	18	
		1994	0.7447	13	0.5113	13	

NA* = no samples in "low-use" month-group stratum
NA** = only one sample in stratum
NA*** = no samples in stratum
NA**** = no samples in "high-use" month-group stratum
NA***** = no harvesters observed in any of the samples

Appendix Table 8. Empirical tests of the former "month-group" stratification on selected beaches that were open in both the former "high-use" and "low-use" months. Estimates were made for each beach using two methods: (1) the month-group and tide-day strata, and (2) only the three tide-day strata. Wolfe Property SP and Fort Flagler SP could not be compared in 1999 because they were only open during "low-use" months. Shaded values indicate cases in which the former month-group stratification produced a lower RSE (relative standard error) than the tide-day stratification alone.

			RSE of stratified mean daily effort		Stratified mean daily effort	
BIDN	**Beach Name**	**Year**	***Stratified by month-group***	***Not stratified by month-group***	***Stratified by month-group***	***Not stratified by month-group***
200060	**Birch Bay SP**	2001	ERR*	0.10	ERR**	106.89
		2000	0.10	0.10	81.01	81.32
		1999	0.14	0.15	75.38	77.64
		1998	0.10	0.10	214.34	213.89
240150	**West Penn Cove**	2001	ERR***	0.11	41.54	40.91
		2000	0.10	0.07	44.68	44.35
		1999	0.14	0.13	39.22	39.68
		1998	0.15	0.16	82.84	87.54
240160	**Long Point**	2001	ERR***	0.21	10.79	10.25
		2000	0.09	0.10	18.47	20.06
		1999	0.16	0.13	18.77	18.93
		1998	0.18	0.18	33.20	33.96
240440	**Freeland CP**	2001	ERR***	0.15	30.53	31.23
		2000	0.10	0.10	27.67	28.08
		1999	0.13	0.12	21.06	20.54
		1998	0.14	0.13	45.43	46.01
240520	**WINAS-Maylor Pt-East**	2001	ERR***	0.13	24.68	25.18
		2000	0.09	0.10	29.42	32.54
		1999	0.09	0.10	21.29	22.58
		1998	0.11	0.12	43.86	46.07
250510	**Wolfe Property SP**	2001	ERR*	0.15	ERR*	34.86
		2000	ERR*	0.12	62.91	60.88
		1999	NA	NA	NA	NA
		1998	0.18	0.16	68.38	65.65
250260	**Fort Flagler SP**	2001	ERR*	0.15	65.10	62.86
		2000	ERR*	0.11	48.54	48.90
		1999	NA	NA	NA	NA
		1998	0.12	0.15	34.32	38.48
260110	**Double Bluffs SP**	2001	ERR*	0.14	12.56	12.44
		2000	0.13	0.12	10.60	10.95
		1999	0.12	0.12	15.07	15.32
		1998	0.14	0.15	43.52	44.21
270200	**Dosewallips SP**	2001	ERR***	0.15	103.02	99.24
		2000	ERR***	ERR****	79.17	75.83
		1999	0.06	0.07	97.34	96.28
		1998	0.13	0.11	96.24	96.02
270440	**Potlatch SP**	2001	ERR*	0.12	ERR*	98.81
		2000	ERR*	0.11	59.63	59.96
		1999	0.16	0.14	101.03	99.39
		1998	0.08	0.08	141.44	143.85
270210	**Seal Rock FSC**	2001	ERR***	0.14	18.37	18.16
		2000	0.29	0.29	29.37	30.37
		1999	0.17	0.15	29.51	28.37
		1998	0.16	0.18	27.72	32.94
270500	**Quilcene Tidelands**	2001	ERR***	0.10	26.56	27.49
		2000	0.21	0.20	51.84	50.56
		1999	0.13	0.12	21.63	22.94
		1998	0.15	0.14	20.31	18.95
270460	**Twanoh SP**	2001	ERR***	0.12	52.95	54.60
		2000	0.12	0.10	64.58	64.67
		1999	0.11	0.11	70.99	71.19
		1998	0.14	0.13	66.79	66.05
	Mean of all values:				**51.57**	**51.86**

ERR* = no sample from any of the tides in the LOW tide-day/ "low-use" month-group stratum.
ERR** = no sample from any of the tides in the LOW tide-day/ "low-use" month-group stratum; only 1 sample from the two tides in the ELOW tide-day/ "low-use" month-group stratum.
ERR*** = only one sample from the tides in the ELOW tide-day/ "low-use" month-group stratum.
ERR**** = only one sample from the two tides in the ELOW tide-day stratum.

Appendix Table 9. Ratio of observed effort (E_t) during all tides lower than 2.0 ft and "plus tides" ($\geq$2.0 ft) on 14 public beaches where plus-tide effort was observed during flights in 1993 and 1994. All data from season = OO (open for both clams and oysters). Data do not include five beaches where no plus-tide effort was observed. Data do not include beaches where less than five flights per stratum (all tides and plus tides) were completed.

BIDN	BEACH NAME	Mean observed effort		Ratio of observed effort on Plus tides to all other tides
		All tides	Plus tides	
250050	Sequim Bay SP	4.4444	1.2000	0.2700
250400	Oak Bay CP	11.1765	0.7500	0.0671
250410	South Indian Island CP	8.0385	0.7778	0.0968
250510	Wolfe Property SP	10.2667	1.3333	0.1299
270060	South Zelatched Point	1.1020	0.3333	0.3025
270080	Toandos Peninsula SP	7.9388	0.3333	0.0420
270200	Dosewallips SP	39.6429	14.1000	0.3557
270210	Seal Rock FSC	8.1000	0.7778	0.0960
270230	Kitsap Memorial SP	5.4118	1.0000	0.1848
270370	DNR-48	2.4694	0.6667	0.2700
270410	Scenic Beach SP	3.0455	0.1429	0.0469
270440	Potlatch SP	44.5610	9.8000	0.2199
270442	Potlatch DNR	9.8033	1.7500	0.1785
270480	Rendsland Creek	6.9302	0.4000	0.0577
	Mean of ratios			**0.1656**
	Median of ratios			**0.1542**

Appendix Table 10. Summary ANOVA results testing effect of the former tide strata on Manila clam CPUE. Former tide strata codes: e = extreme low, l = low, h = high. * = significant test at α = 0.05 level. ** = significant test at α = 0.01 level.

BIDN	Beach Name	*Year*	*Model (group) DF*	*Error DF*	*F-value*	*P > F*		*Tide strata compared*
200060	Birch Bay SP	1998	2	11	4.29	0.0420	*	e,l,h
200060	Birch Bay SP	1999	1	6	1.88	0.2189		l,h
200060	Birch Bay SP	2000	1	2	3.03	0.2241		l,h
240440	Freeland CP	2000	1	2	3.89	0.1874		l,h
250050	Sequim Bay SP	1998	1	4	0.38	0.5701		l,h
250050	Sequim Bay SP	1999	1	3	0.62	0.4877		l,h
250050	Sequim Bay SP	2000	1	5	0.03	0.8794		e,l
250055	North Sequim Bay SP	1998	1	3	0.04	0.8623		l,h
250055	North Sequim Bay SP	2000	1	5	0.52	0.5028		e,l
250400	Oak Bay CP	1998	2	6	0.03	0.9667		e,l,h
250400	Oak Bay CP	1999	2	5	0.11	0.8943		e,l,h
250400	Oak Bay CP	2000	2	7	1.58	0.2721		e,l,h
250410	South Indian Island CP	1998	2	10	0.49	0.6271		e,l,h
250410	South Indian Island CP	1999	1	4	0.26	0.6400		l,h
250410	South Indian Island CP	2000	1	4	0.75	0.4356		l,h
250510	Wolfe Property SP	1998	1	3	0.18	0.7021		l,h
250510	Wolfe Property SP	1999	1	6	0.29	0.6089		l,h
250510	Wolfe Property SP	2000	2	6	18.15	0.0029	**	e,l,h
250512	Shine Tidelands SP	1998	2	8	0.14	0.8751		e,l,h
250512	Shine Tidelands SP	1999	2	5	1.95	0.2372		e,l,h
250512	Shine Tidelands SP	2000	1	5	1.31	0.3043		l,h
260380	Illahee SP	1998	2	6	1.51	0.2942		e,l,h
260380	Illahee SP	2000	2	6	0.77	0.5058		e,l,h
270170	Pt Whitney Tidelands	1998	1	2	4.03	0.1825		l,h
270200	Dosewallips SP	1999	1	7	0.30	0.6002		l,h
270200	Dosewallips SP	2000	2	5	1.87	0.2463		e,l,h
270293	Triton Cove Tidelands	2000	2	5	0.30	0.7523		e,l,h
270300	Eagle Creek	2000	1	4	0.81	0.4181		l,h
270380	DNR 44-A W Dewatto	1998	1	7	7.22	0.0313	*	l,h
270440	Potlatch SP	1998	1	5	1.49	0.2770		l,h
270440	Potlatch SP	1999	1	8	0.36	0.5636		l,h
270440	Potlatch SP	2000	2	6	2.32	0.1789		e,l,h
270442	Potlatch DNR	1998	1	3	0.45	0.5507		l,h
270442	Potlatch DNR	2000	1	4	1.94	0.2363		e,l
270480	Rendsland Creek	1998	2	7	0.80	0.4873		e,l,h
270480	Rendsland Creek	2000	1	4	0.23	0.6586		l,h
270500	Quilcene Tidelands	1998	2	17	1.10	0.3562		e,l,h
270500	Quilcene Tidelands	1999	2	13	0.33	0.7215		e,l,h
280680	Penrose Point SP	1999	2	5	1.43	0.3236		e,l,h
280710	North Bay	2000	1	3	0.12	0.7560		e,l
281043	Oakland Bay Ogg	2000	2	6	1.98	0.2182		e,l,h
281140	Frye Cove CP	2000	2	6	2.23	0.1882		e,l,h

Appendix Table 11. Summary ANOVA results testing effect of the former tide strata on native littleneck CPUE. Former tide strata codes: e = extreme low, l = low, h = high. * = significant test at α = 0.05 level. ** = significant test at α = 0.01 level.

BIDN	**Beach Name**	*Year*	*Model (group) DF*	*Error DF*	*F-value*	*P > F*		*Tide strata compared*
200060	Birch Bay SP	1998	2	11	0.44	0.6550		e,l,h
200060	Birch Bay SP	1999	1	6	0.00	0.9929		l,h
200060	Birch Bay SP	2000	1	2	0.62	0.5127		l,h
220422	North English Camp	1999	1	3	1.99	0.2529		e,l
240030	Camano Island SP	1998	1	4	0.49	0.5208		l,h
240030	Camano Island SP	2000	1	3	0.09	0.7788		l,h
240150	West Penn Cove	1998	2	9	2.70	0.1204		e,l,h
240150	West Penn Cove	1999	2	6	0.40	0.6896		e,l,h
240150	West Penn Cove	2000	1	4	1.73	0.2586		l,h
240160	Long Point	1999	1	4	0.66	0.4622		e,l
240260	Ala (Ben Ure) Spit	1998	1	9	5.50	0.0436	*	l,h
240260	Ala (Ben Ure) Spit	1999	1	4	2.47	0.1914		l,h
240260	Ala (Ben Ure) Spit	2000	1	3	4.29	0.1302		e,l
240440	Freeland CP	2000	1	2	2.59	0.2489		l,h
240520	WINAS-Maylor Pt East	1998	2	7	0.32	0.7375		e,l,h
240520	WINAS-Maylor Pt East	1999	1	4	0.46	0.5358		e,l
250050	Sequim Bay SP	1998	1	4	2.76	0.1720		l,h
250050	Sequim Bay SP	1999	1	3	0.47	0.5414		l,h
250050	Sequim Bay SP	2000	1	5	0.02	0.8983		e,l
250055	North Sequim Bay SP	1998	1	3	0.01	0.9446		l,h
250055	North Sequim Bay SP	2000	1	5	1.87	0.2296		e,l
250260	Fort Flagler SP	1998	2	5	0.19	0.8288		e,l,h
250260	Fort Flagler SP	1999	1	4	1.13	0.3468		l,h
250400	Oak Bay CP	1998	2	6	0.42	0.6727		e,l,h
250400	Oak Bay CP	1999	2	5	2.23	0.2032		e,l,h
250400	Oak Bay CP	2000	2	7	0.51	0.6206		e,l,h
250410	South Indian Island CP	1998	2	10	3.08	0.0906		e,l,h
250410	South Indian Island CP	1999	1	4	1.93	0.2372		l,h
250410	South Indian Island CP	2000	1	4	0.84	0.4107		l,h
250470	P.T. Ship Canal East	1998	2	5	0.44	0.6690		e,l,h
250470	P.T. Ship Canal East	1999	2	5	0.71	0.5339		e,l,h
250470	P.T. Ship Canal East	2000	2	6	2.95	0.1281		e,l,h
250510	Wolfe Property SP	1998	1	3	1.20	0.3537		l,h
250510	Wolfe Property SP	1999	1	6	0.01	0.9325		l,h
250510	Wolfe Property SP	2000	2	6	0.67	0.5467		e,l,h
250512	Shine Tidelands SP	1998	2	8	0.30	0.7494		e,l,h
250512	Shine Tidelands SP	1999	2	5	0.64	0.5678		e,l,h
250512	Shine Tidelands SP	2000	1	5	0.05	0.8311		l,h
260110	Double Bluffs SP	1999	2	5	0.63	0.5704		e,l,h
260380	Illahee SP	1998	2	6	0.90	0.4542		e,l,h
260380	Illahee SP	2000	2	6	0.82	0.4852		e,l,h
270050	DNR 57-B Brown Point	1998	1	5	0.45	0.5330		l,h
270230	Kitsap Memorial SP	1998	2	5	0.99	0.4339		e,l,h
270230	Kitsap Memorial SP	1999	2	7	1.57	0.2725		e,l,h
270230	Kitsap Memorial SP	2000	1	3	1.52	0.3049		e,l
270293	Triton Cove Tidelands	2000	2	5	1.50	0.3087		e,l,h
270300	Eagle Creek	2000	1	4	0.80	0.4224		l,h
270380	DNR 44-A W Dewatto	1998	1	7	1.25	0.2997		l,h
270440	Potlatch SP	1998	1	5	3.77	0.1099		l,h
270440	Potlatch SP	1999	1	8	16.08	0.0039	**	l,h
270440	Potlatch SP	2000	2	6	0.81	0.4879		e,l,h
270442	Potlatch DNR	1998	1	3	0.53	0.5178		l,h
270442	Potlatch DNR	2000	1	4	0.74	0.4391		e,l
270480	Rendsland Creek	1998	2	7	0.26	0.7791		e,l,h
270480	Rendsland Creek	2000	1	4	6.73	0.0604		l,h
280680	Penrose Point SP	1999	2	5	0.40	0.6873		e,l,h
280710	North Bay	2000	1	3	0.71	0.4620		e,l
281140	Frye Cove CP	2000	2	6	3.18	0.1145		e,l,h

Appendix Table 12. Summary ANOVA results testing effect of the former tide strata on combined Manila and native littleneck CPUE. Former tide strata codes: e = extreme low, l = low, h = high. * = significant test at α = 0.05 level. ** = significant test at α = 0.01 level.

BIDN	Beach Name	*Year*	*Model (group) DF*	*Error DF*	*F-value*	*P > F*		*Tide strata compared*
200060	Birch Bay SP	1998	2	11	1.34	0.3022		e,l,h
200060	Birch Bay SP	1999	1	6	0.01	0.9263		l,h
200060	Birch Bay SP	2000	1	2	0.22	0.6824		l,h
240440	Freeland CP	2000	1	2	4.49	0.1682		l,h
250050	Sequim Bay SP	1998	1	4	2.78	0.1707		l,h
250050	Sequim Bay SP	1999	1	3	0.39	0.5762		l,h
250050	Sequim Bay SP	2000	1	5	0.02	0.9029		e,l
250055	North Sequim Bay SP	1998	1	3	0.00	0.9538		l,h
250055	North Sequim Bay SP	2000	1	5	1.90	0.2264		e,l
250400	Oak Bay CP	1998	2	6	0.75	0.5138		e,l,h
250400	Oak Bay CP	1999	2	5	1.94	0.2373		e,l,h
250400	Oak Bay CP	2000	2	7	0.08	0.9220		e,l,h
250410	South Indian Island CP	1998	2	10	2.90	0.1015		e,l,h
250410	South Indian Island CP	1999	1	4	0.57	0.4906		l,h
250410	South Indian Island CP	2000	1	4	0.97	0.3797		l,h
250510	Wolfe Property SP	1998	1	3	0.01	0.9110		l,h
250510	Wolfe Property SP	1999	1	6	0.26	0.6266		l,h
250510	Wolfe Property SP	2000	2	6	15.14	0.0045	**	e,l,h
250512	Shine Tidelands SP	1998	2	8	0.41	0.6753		e,l,h
250512	Shine Tidelands SP	1999	2	5	1.18	0.3813		e,l,h
250512	Shine Tidelands SP	2000	1	5	0.00	0.9499		l,h
260380	Illahee SP	1998	2	6	1.36	0.3253		e,l,h
260380	Illahee SP	2000	2	6	0.44	0.6614		e,l,h
270200	Dosewallips SP	1999	1	7	0.25	0.6327		l,h
270200	Dosewallips SP	2000	2	5	2.09	0.2191		e,l,h
270293	Triton Cove Tidelands	2000	2	5	2.34	0.1913		e,l,h
270300	Eagle Creek	2000	1	4	0.02	0.9044		l,h
270380	DNR 44-A W Dewatto	1998	1	7	4.52	0.0711		l,h
270440	Potlatch SP	1998	1	5	3.02	0.1425		l,h
270440	Potlatch SP	1999	1	8	13.55	0.0062	**	l,h
270440	Potlatch SP	2000	2	6	1.28	0.3445		e,l,h
270442	Potlatch DNR	1998	1	3	0.93	0.4067		l,h
270442	Potlatch DNR	2000	1	4	0.90	0.3954		e,l
270480	Rendsland Creek	1998	2	7	0.25	0.7838		e,l,h
270480	Rendsland Creek	2000	1	4	0.11	0.7542		l,h
280680	Penrose Point SP	1999	2	5	1.31	0.3479		e,l,h
280710	North Bay	2000	1	3	0.00	0.9688		e,l
281140	Frye Cove CP	2000	2	6	3.19	0.1140		e,l,h

Appendix Table 13. Summary ANOVA results testing effect of the former tide strata on butter clam CPUE. Former tide strata codes: e = extreme low, l = low, h = high. * = significant test at α = 0.05 level. ** = significant test at α = 0.01 level.

BIDN	**Beach Name**	*Year*	*Model (group) DF*	*Error DF*	*F-value*	*P > F*		*Tide strata compared*
200060	Birch Bay SP	1998	2	11	6.25	0.0153	*	e,l,h
200060	Birch Bay SP	1999	1	6	2.71	0.1507		l,h
200060	Birch Bay SP	2000	1	2	0.20	0.6965		l,h
240030	Camano Island SP	1998	1	4	15.35	0.0173	*	l,h
240030	Camano Island SP	2000	1	3	0.13	0.7423		l,h
240150	West Penn Cove	1998	2	9	14.17	0.0017	**	e,l,h
240150	West Penn Cove	1999	2	6	5.71	0.0410	*	e,l,h
240150	West Penn Cove	2000	1	4	0.16	0.7085		l,h
240160	Long Point	1999	1	4	15.52	0.0170	*	e,l
240260	Ala (Ben Ure) Spit	1998	1	9	1.53	0.2481		l,h
240260	Ala (Ben Ure) Spit	1999	1	4	0.95	0.3843		l,h
240260	Ala (Ben Ure) Spit	2000	1	3	0.83	0.4292		e,l
240440	Freeland CP	2000	1	2	0.07	0.8129		l,h
240520	WINAS-Maylor Pt East	1998	2	7	5.02	0.0445	*	e,l,h
240520	WINAS-Maylor Pt East	1999	1	4	1.56	0.2792		e,l
250260	Fort Flagler SP	1998	2	5	12.34	0.0117	*	e,l,h
250260	Fort Flagler SP	1999	1	4	3.26	0.1455		l,h
250400	Oak Bay CP	1998	2	6	1.14	0.3794		e,l,h
250400	Oak Bay CP	1999	2	5	0.02	0.9834		e,l,h
250400	Oak Bay CP	2000	2	7	2.88	0.1220		e,l,h
250410	South Indian Island CP	1998	2	10	6.54	0.0153	*	e,l,h
250410	South Indian Island CP	1999	1	4	0.00	0.9745		l,h
250410	South Indian Island CP	2000	1	4	0.11	0.7577		l,h
250470	P.T. Ship Canal East	1998	2	5	0.45	0.6619		e,l,h
250470	P.T. Ship Canal East	1999	2	5	1.01	0.4296		e,l,h
250470	P.T. Ship Canal East	2000	2	6	6.86	0.0282	*	e,l,h
250512	Shine Tidelands SP	1998	2	8	3.77	0.0702		e,l,h
250512	Shine Tidelands SP	1999	2	5	2.65	0.1642		e,l,h
250512	Shine Tidelands SP	2000	1	5	0.51	0.5060		l,h
260110	Double Bluffs SP	1999	2	5	0.19	0.8319		e,l,h
270050	DNR 57-B Brown Point	1998	1	5	2.71	0.1609		l,h
270230	Kitsap Memorial SP	1998	2	5	5.31	0.0580		e,l,h
270230	Kitsap Memorial SP	1999	2	7	0.44	0.6618		e,l,h
270230	Kitsap Memorial SP	2000	1	3	0.74	0.4520		e,l
270440	Potlatch SP	1998	1	5	8.54	0.0329	*	l,h
270440	Potlatch SP	1999	1	8	0.00	0.9580		l,h
270440	Potlatch SP	2000	2	6	2.18	0.1942		e,l,h
270442	Potlatch DNR	1998	1	3	0.12	0.7488		l,h
270442	Potlatch DNR	2000	1	4	0.56	0.4976		e,l
280680	Penrose Point SP	1999	2	5	1.84	0.2525		e,l,h

Appendix Table 14. Summary ANOVA results testing effect of the former tide strata on Pacific oyster CPUE. Former tide strata codes: e = extreme low, l = low, h = high. * = significant test at α = 0.05 level. ** = significant test at α = 0.01 level.

BIDN	Beach Name	*Year*	*Model (group) DF*	*Error DF*	*F-value*	*P > F*		*Tide strata compared*
250050	Sequim Bay SP	1998	1	4	4.56	0.0997		l,h
250050	Sequim Bay SP	1999	1	3	0.17	0.7073		l,h
250050	Sequim Bay SP	2000	1	5	0.47	0.5231		e,l
250055	North Sequim Bay SP	1998	1	3	0.28	0.6344		l,h
250055	North Sequim Bay SP	2000	1	5	4.52	0.0870		e,l
250510	Wolfe Property SP	1998	1	3	11.47	0.0429	*	l,h
250510	Wolfe Property SP	1999	1	6	5.18	0.0632		l,h
250510	Wolfe Property SP	2000	2	6	0.36	0.7123		e,l,h
260380	Illahee SP	1998	2	7	0.61	0.5704		e,l,h
260380	Illahee SP	2000	2	6	0.31	0.7479		e,l,h
270170	Pt Whitney Tidelands	1998	1	5	3.06	0.1404		l,h
270170	Pt Whitney Tidelands	2000	2	5	0.59	0.5872		e,l,h
270200	Dosewallips SP	1999	1	7	2.37	0.1676		l,h
270200	Dosewallips SP	2000	2	7	2.05	0.1998		e,l,h
270210	Seal Rock FSC	1999	2	7	0.38	0.6989		e,l,h
270230	Kitsap Memorial SP	1998	2	6	20.14	0.0022	**	e,l,h
270230	Kitsap Memorial SP	1999	2	7	0.69	0.5318		e,l,h
270230	Kitsap Memorial SP	2000	2	5	0.15	0.8661		e,l,h
270293	Triton Cove Tidelands	2000	2	6	0.72	0.5265		e,l,h
270300	Eagle Creek	2000	2	6	2.10	0.2039		e,l,h
270380	DNR 44-A W Dewatto	1998	1	7	0.66	0.4426		l,h
270380	DNR 44-A W Dewatto	2000	2	4	2.17	0.2298		e,l,h
270440	Potlatch SP	1998	1	5	4.35	0.0915		l,h
270440	Potlatch SP	1999	1	8	0.01	0.9328		l,h
270440	Potlatch SP	2000	2	6	2.92	0.1300		e,l,h
270460	Twanoh SP	1998	1	3	1.47	0.3122		l,h
270460	Twanoh SP	1999	2	6	0.37	0.7080		e,l,h
270480	Rendsland Creek	1998	2	7	0.28	0.7610		e,l,h
270480	Rendsland Creek	1999	1	4	2.91	0.1635		l,h
270480	Rendsland Creek	2000	2	6	0.49	0.6371		e,l,h
280680	Penrose Point SP	1999	2	5	1.40	0.3290		e,l,h
280710	North Bay	2000	1	3	0.11	0.7637		e,l
281043	Oakland Bay Ogg	2000	2	6	0.04	0.9625		e,l,h
281140	Frye Cove CP	2000	2	6	0.07	0.9348		e,l,h

Appendix Table 15. Results of one-way ANOVAs comparing mean CPUE on weekdays versus mean CPUE on weekends. Data are pooled from 1998, 1999 and 2000 creel surveys. Mean CPUE for clams in pounds/harvester. Mean CPUE for oysters is in number/harvester. ** = significant test at α = 0.01 level.

BIDN	Beach Name	N (surveys)		Mean CPUE		F-value	*P > F*		Species
		Wkdays	Wkends	Wkdays	Wkends				
270380	DNR 44-A W Dewatto	13	3	16.58	14.26	1.71	0.2116		Oyster
270300	Eagle Creek	13	6	15.09	14.74	0.02	0.8796		Oyster
260380	Illahee SP	16	3	12.78	11.89	0.48	0.4961		Oyster
270170	Pt Whitney Tidelands	15	3	14.37	16.84	0.87	0.3661		Oyster
270460	Twanoh SP	10	4	17.02	16.22	0.51	0.4892		Oyster
250055	North Sequim Bay SP	10	4	2.59	2.55	0.01	0.9432		Native
250400	Oak Bay CP	21	6	1.18	0.96	0.50	0.4842		Native
270440	Potlatch SP	20	6	0.73	0.70	0.02	0.8917		Native
270442	Potlatch DNR	12	3	1.38	1.29	0.02	0.8784		Native
250050	Sequim Bay SP	16	5	2.28	2.21	0.03	0.8661		Native
250410	South Indian Island CP	21	5	1.29	1.09	0.80	0.3787		Native
250512	Shine Tidelands SP	21	5	0.85	0.78	0.11	0.7384		Native
270500	Quilcene Tidelands	26	10	1.86	1.87	0.00	0.9617		Manila
281043	Oakland Bay Ogg	6	3	2.15	1.75	1.14	0.3220		Manila
280680	Penrose Point SP	5	3	0.76	0.54	0.37	0.5635		Manila
270480	Rendsland Creek	18	5	0.32	0.17	0.28	0.6014		Manila
270293	Triton Cove Tidelands	5	3	0.64	0.60	0.01	0.9112		Manila
250510	Wolfe Property SP	15	7	1.34	1.52	0.25	0.6234		Manila
270200	Dosewallips SP	19	3	2.07	2.21	0.14	0.7143		Manila
270050	DNR 57-B Brown Point	4	3	3.42	5.52	0.63	0.4621		Butter
250470	P.T. Ship Canal East	19	6	6.44	3.62	10.00	0.0044	**	Butter

Appendix Table 16. Results of one-way ANOVAs comparing mean CPUE on weekend extreme low tides (ELOW stratum) versus other tide-day strata combined. Data are pooled from 1998, 1999 and 2000 creel surveys. Mean CPUE for clams is in pounds/harvester. Mean CPUE for oysters is in number/harvester. * = significant test at α = 0.05 level.

BIDN	Beach Name	N (surveys)		Mean CPUE		F-value	*P > F*		Species
		ELOW	Other strata	ELOW	Other strata				
270300	Eagle Creek	2	25	15.95	15.04	0.09	0.7708		Oyster
270170	Pt Whitney Tidelands	2	25	16.59	12.07	1.11	0.3030		Oyster
270230	Kitsap Memorial SP	2	25	11.15	9.93	0.09	0.7626		Oyster
270480	Rendsland Creek	3	30	15.22	14.93	0.01	0.9082		Oyster
250260	Fort Flagler SP	2	19	2.08	2.35	0.12	0.7323		Native
260110	Double Bluffs SP	2	17	0.30	0.60	0.78	0.3897		Native
250400	Oak Bay CP	3	24	0.80	1.17	0.84	0.3689		Native
250050	Sequim Bay SP	2	26	2.44	2.45	0.00	0.9838		Native
250410	South Indian Island CP	2	33	0.87	1.23	1.30	0.2628		Native
240160	Long Point	3	10	0.54	0.85	0.39	0.5463		Native
281043	Oakland Bay Ogg	2	20	1.36	2.06	6.93	0.0160	*	Manila
270293	Triton Cove Tidelands	2	6	0.78	0.57	0.31	0.6002		Manila
270200	Dosewallips SP	3	29	2.21	2.12	0.09	0.7717		Manila
250410	South Indian Island CP	2	33	0.38	0.27	0.20	0.6612		Manila
250470	P.T. Ship Canal East	2	27	4.94	5.73	0.22	0.6414		Butter
240160	Long Point	3	10	8.43	5.99	1.51	0.2450		Butter

Appendix Table 17. Sample size, mean CPUE and relative standard error (RSE) of CPUE for Manila and native littleneck clams from creel surveys conducted in year 2000 (except where noted at important clamming beaches.

BIDN	Beach Name	N creel surveys	Dominant species	Mean CPUE	RSE of CPUE	% dominant species in creel
270200	Dosewallips SP	8	Manila	1.93	0.1	98
270500	Quilcene Tidelands*	16	Manila	1.53	0.05	98
240440	Freeland CP	5	Manila	2.53	0.12	83
280710	North Bay	6	Manila	1.79	0.17	92
280143	Oakland Bay Ogg	9	Manila	2.02	0.09	100
270293	Triton Cove Tidelands	8	Manila	0.62	0.25	51
250510	Wolfe Property SP	9	Manila	0.94	0.19	51
200060	Birch Bay SP	5	Native	1.73	0.08	71
270440	Potlatch SP	9	Native	0.94	0.16	61
250260	Fort Flagler SP*	6	Native	2.51	0.16	85
250512	Shine Tidelands SP	7	Native	0.78	0.17	51
240030	Camano Island SP	6	Native	1.32	0.11	44
240580	Kayak Point CP**	6	Native	1.85	0.15	80
240150	West Penn Cove	6	Native	1.52	0.14	71
250055	North Sequim Bay SP	8	Native	2.46	0.15	91
250050	Sequim Bay SP	8	Native	2.23	0.08	91
250410	South Indian Island CP	6	Native	1.1	0.22	63
240520	WINAS-Maylor Pt East	4	Native	0.6	0.27	41
Mean		**7.33**		**1.58**	**0.15**	

Appendix Table 18. Results of one-way ANOVAs testing the effect of creel survey year on Manila clam CPUE (pounds per harvester) at 20 public beaches. * = significant test at α = 0.05 level. ** = significant test at α = 0.10 level.

BIDN	Beach Name	*Model (group) DF*	*Error DF*	*F-value*	*P > F*		*Years analyzed*
200060	Birch Bay SP	3	30	0.38	0.7673		1998-2001
240580	Kayak Point CP	3	11	1.39	0.2976		1998-2001
250050	Sequim Bay SP	3	24	0.03	0.9910		1998-2001
250410	South Indian Island CP	3	31	1.01	0.4020		1998-2001
250510	Wolfe Property SP	3	24	7.11	0.0014	**	1998-2001
250512	Shine Tidelands SP	3	27	2.05	0.1305		1998-2001
270200	Dosewallips SP	3	28	0.97	0.4219		1998-2001
270300	Eagle Creek	3	16	0.17	0.9135		1998-2001
270440	Potlatch SP	3	30	0.85	0.4772		1998-2001
270442	Potlatch DNR	3	13	2.90	0.0752		1998-2001
270480	Rendsland Creek	3	20	1.47	0.2536		1998-2001
220422	North English Camp	2	8	0.67	0.5375		1999-2001
240440	Freeland CP	2	18	1.45	0.2596		1999-2001
250400	Oak Bay CP	2	24	0.03	0.9676		1998-2000
270170	Pt Whitney Tidelands	2	12	0.17	0.8435		1998,2000,2001
270230	Kitsap Memorial SP	2	18	1.04	0.3746		1998-2000
270380	DNR 44-A W Dewatto	2	10	1.35	0.3037		1998,2000,2001
270500	Quilcene Tidelands	2	43	6.40	0.0037	**	1998,1999,2001
250055	North Sequim Bay SP	1	12	1.76	0.2097		1998,2000
281043	Oakland Bay Ogg	1	20	0.06	0.8128		2000,2001

Appendix Table 19. Results of one-way ANOVAs testing the effect of creel survey year on native littleneck CPUE (pounds per harvester) at 28 public beaches. * = significant test at α = 0.05 level. ** = significant test at α = 0.10 level.

BIDN	**Beach Name**	*Model (group) DF*	*Error DF*	*F-value*	*P > F*		*Years analyzed*
200060	Birch Bay SP	3	30	1.95	0.1435		1998-2001
220050	Spencer Spit SP	3	7	0.76	0.5503		1998-2001
240030	Camano Island SP	3	19	13.52	0.0001	**	1998-2001
240150	West Penn Cove	3	29	1.62	0.2072		1998-2001
240260	Ala (Ben Ure) Spit	3	25	0.51	0.6781		1998-2001
240520	WINAS-Maylor Pt East	3	22	2.76	0.0664		1998-2001
240580	Kayak Point CP	3	11	1.97	0.1769		1998-2001
250050	Sequim Bay SP	3	24	1.91	0.1554		1998-2001
250410	South Indian Island CP	3	31	0.90	0.4532		1998-2001
250470	P.T. Ship Canal East	3	25	0.92	0.4454		1998-2001
250510	Wolfe Property SP	3	24	0.69	0.5669		1998-2001
250512	Shine Tidelands SP	3	27	1.58	0.2174		1998-2001
260110	Double Bluffs SP	3	15	0.61	0.6184		1998-2001
270200	Dosewallips SP	3	28	0.93	0.4380		1998-2001
270230	Kitsap Memorial SP	3	18	2.48	0.1123		1998-2001
270300	Eagle Creek	3	16	0.84	0.4932		1998-2001
270440	Potlatch SP	3	30	1.47	0.2422		1998-2001
270442	Potlatch DNR	3	13	3.95	0.0332	*	1998-2001
270480	Rendsland Creek	3	20	1.98	0.1499		1998-2001
220422	North English Camp	2	8	0.99	0.4126		1999-2001
240160	Long Point	2	10	2.88	0.1030		1999-2001
240440	Freeland CP	2	18	1.39	0.2742		1999-2001
250260	Fort Flagler SP	2	18	0.19	0.8295		1998,1999,2001
250400	Oak Bay CP	2	24	0.05	0.9521		1998-2000
270170	Pt Whitney Tidelands	2	12	2.73	0.1055		1998,2000,2001
270380	DNR 44-A W Dewatto	2	10	0.74	0.5000		1998,2000,2001
250055	North Sequim Bay SP	1	12	0.38	0.5477		1998,2000
270050	DNR 57-B Brown Point	1	14	0.00	0.9705		1998,2001

Appendix Table 20. Results of one-way ANOVAs testing the effect of creel survey year on Pacific oyster CPUE (number per harvester) at 15 public beaches. * = significant test at α = 0.05 level. ** = significant test at α = 0.10 level.

BIDN	**Beach Name**	*Model (group) DF*	*Error DF*	*F-value*	*P > F*		**Years analyzed**
200060	Birch Bay SP	3	30	1.16	0.3396		1998-2001
250050	Sequim Bay SP	3	24	3.92	0.0208	*	1998-2001
250410	South Indian Island CP	3	31	1.11	0.3614		1998-2001
250510	Wolfe Property SP	3	27	2.36	0.0933		1998-2001
250512	Shine Tidelands SP	3	27	1.46	0.2463		1998-2001
270300	Eagle Creek	3	23	0.38	0.7673		1998-2001
270440	Potlatch SP	3	31	1.78	0.1719		1998-2001
270480	Rendsland Creek	3	29	1.20	0.3289		1998-2001
250400	Oak Bay CP	2	24	0.40	0.6746		1998-2000
270170	Pt Whitney Tidelands	2	24	6.26	0.0065	*	1998,2000,2001
270200	Dosewallips SP	2	27	7.77	0.0022	**	1999-2001
270230	Kitsap Memorial SP	2	24	0.52	0.6010		1998-2000
270380	DNR 44-A W Dewatto	2	15	2.98	0.0815		1998,2000,2001
250055	North Sequim Bay SP	1	12	0.71	0.4145		1998,2000
270210	Seal Rock FSC	1	19	0.40	0.5361		2000,2001