Tower Counts

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Background and Objectives

Rationale

Counting towers provide an accurate, low-cost, low-maintenance, low-technology, and easily mobilized escapement estimation program compared to other methods (e.g., weirs, hydroacoustics, mark–recapture, and aerial surveys) (Thompson 1962; Siebel 1967; Cousens et al. 1982; Symons and Waldichuk 1984; Anderson 2000; Alaska Department of Fish and Game 2003). Counting tower data has been found to be consistent with that of digital video counts (Edwards 2005). Counting towers do not interfere with natural fish migration patterns, nor are fish handled or stressed; however, their use is generally limited to clear rivers that meet specific site selection criteria.

The data provided by counting tower sampling allow fishery managers to

- determine reproductive population size,
- estimate total return (escapement + catch) and its uncertainty,
- evaluate population productivity and trends,
- set harvest rates,
- determine spawning escapement goals, and
- forecast future returns (Alaska Department of Fish and Game 1974–2000 and 1975–2004).

The number of spawning fish is determined by subtracting subsistence, sport-caught fish, and prespawn mortality from the total estimated escapement.

The methods outlined in this protocol for tower counts can be used to provide reasonable estimates (± 6%–10%) of reproductive salmon population size and run timing in clear rivers.

Objective

Tower counts enable practitioners to systematically sample a selected salmon population to estimate reproductive population size and determine run timing.

Background

Counting towers provide an elevated vantage point for visually sampling Pacific salmon spawning migrations. Aluminum scaffolding is typically used (see Figure 1), but biologists are creative and employ tower surrogates, such as tall trees, bridges, dams (see Figure 2), or high river banks to accomplish their sampling. Since the 1950s, counting towers have played a central role in Pacific salmon management in Alaska and to a lesser extent in Canada and Washington (Rietze 1957; Cousens et al. 1982; Anderson 2000; Kohler and Knuepfer 2002; Fair 2004). Towers are used on both single- and multispecies systems (see Table 1) and on small to large (10–130+ m in width) clear water rivers.

TABLE 1. — Sample of counting tower projects for estimating Pacific salmon escapement in Alaska. (ADF&G = Alaska Department of Fish and Game; reference list is not comprehensive but will assist research efforts.)

Location	River	Species	Years in operation	References
Bristol Bay	Egegik	*O. nerka*	1959–present	ADF&G 1974–2004; Anderson 2000
	Igushik	*O. nerka*	1958–present	"
	Kvichak	*O. nerka*	1955–present	"
	Alagnak[1] (branch)	*O. nerka*	1957–1976 2002–present	"
	Newhalen[1]	*O. nerka*	1980–1984 2000–present	Poe and Rogers 1984; Woody 2004
	Tazimina[1]	*O. nerka*	2000–2003	Woody 2004
	Naknek	*O. nerka*	1958–present	ADF&G 1974–2004; Anderson 2000
	Nuyakuk	*O. nerka*	1959–1988 1995–present	"
	Togiak	*O. nerka*	"	"
	Ugashik	*O. nerka*	1957–present	"
	Wood	*O. nerka*	1956–present	"
Norton Sound	Eldorado	*O. kisutch, keta, gorbuscha*		
	Kwiniuk[2]	*O. kisutch, keta, gorbuscha, tshawytshaw*	1965–present	Hamazaki 2003
	Niukluk	*O. kisutch, keta, gorbuscha*		"
	Nome	*O. kisutch, keta, gorbuscha*		"
	Pilgrim	*O. kisutch, keta, gorbuscha*		"
	Snake	*O. kisutch, keta, gorbuscha*	1960–1973	"
Lower Tanana River	Chena	*O. tshawytscha, O. keta*	2002–present	
	Salcha	*O. tshawytscha, O. keta*	2002–present	Tanana Chiefs Conference[3]
	Goodpaster	*O. tshawytscha*	2004–present	"
	Gulkana River	*O. nerka, O. tshawytscha*	2002–present	Taras and Sarafin 2005

[1] Rivers within the Kvichak River watershed.

[2] Not all species were monitored in all years; see review by Hamazaki (2003) for details.

[3] Go to <www.tananachiefs.org/natural/fisheries.html> for contact information.

FIGURE 1. — Example of a counting tower used on the Newhalen River, Bristol Bay, Alaska. This tower is constructed of lightweight aluminum scaffold and is stabilized with guy wires. Here, Libby Baney conducts a 10-minute systematic count.

FIGURE 2. — Example of a counting tower "surrogate" used to estimate escapement on the Chena River, Alaska. Biologists conduct counts from the closest piling. Note contrasting substrate panels that improves visibility of migrating fish. (Photo by the Alaska Department of Fish and Game.)

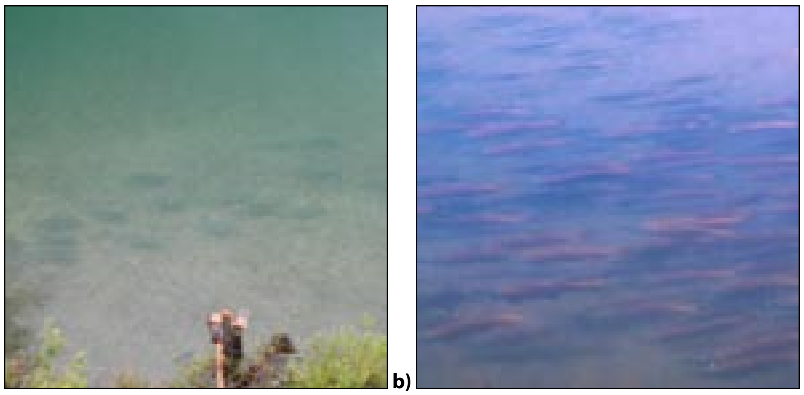
History

Until development of counting towers in the 1950s, estimates of the number of salmon that "escaped" the commercial fishery to spawn (escapement) eluded Alaskan fishery managers. Weirs proved too expensive and difficult to maintain, and they caused excessive delays to salmon returning to their spawning grounds. Estimation methods such as mark–recapture and other indices (e.g., aerial estimates) were expensive, imprecise, and inconsistent (Eicher 1953; Bevan 1960; Thompson 1962; Seibel 1967; Symons and Waldichuk 1984; Cousens et al. 1982).

In 1951 a young fish biologist named Charles Walker reported that he was able to count migrating sockeye salmon *Oncorhynchus nerka* from a high riverbank at the outlet of Lake Alegnegik, on the Wood River in Alaska (Thompson 1962). Rietze (1957) later detailed their migration behavior:

> Fish closely followed the contour of each bank of the river in water about three to six feet deep and rarely more than thirty feet from the shore . . . migrations occurred in a narrow band of about four to ten fish swimming abreast and appearing in a steady stream. The right bank carried . . . the greater number of fish, but sporadically, greater numbers appeared to follow the left bank. There appeared . . . little, if any, crossing from bank to bank . . .

W. F. Thompson, then a director of fisheries research in Bristol Bay, realized that such behavior (see Figure 3) might allow abundance estimates through systematic sampling (Cochran 1977). He proposed this new salmon escapement estimation technique in 1953, conducting a pilot study to test this approach by counting fish from high towers. The pilot study was auspicious, and a series of studies ensued to verify the method's accuracy and to optimize sampling protocols (Fisheries Research Institute 1955; Thompson 1962).



a) b)

FIGURE 3. — Examples of sockeye salmon migration pattern at low (a) and high (b) density. Sockeye salmon generally migrate in a band within 10 m of the shore, making them an ideal candidate for systematic sampling from counting towers.

Accuracy of tower counts was first examined by comparing tower estimates to weir counts (Rietze 1957; Spangler and Rietze 1958); it was assumed that weirs provided total abundance. Rietze (1957) described how, in just a few days, four counting towers were erected on each bank of the Egegik River, both above and below a 230-m picket weir, which took 3 weeks to install. Researchers divided each hour into two systematic 15-min counts, followed by a 15-min break to reduce fatigue and possible error. The sum of 24-h counts was expanded by two for the daily abundance estimate (Rietze 1957). Researchers then defined relative error between tower and weir counts as

$$\frac{\text{tower estimate} - \text{weir count}}{\text{weir count}}$$

Rietze's (1957) estimated relative error was about –7.4% (see Figure 4); however, when he dropped the 2 d it took to build one tower (see Figure 4; 16–17 July) from the comparison, the relative error declined to –1.6%. Tower counts below the weir failed to provide a reliable abundance estimate because natural migration was delayed, causing salmon to mill and rendering accurate counting impossible (see Figure 5).

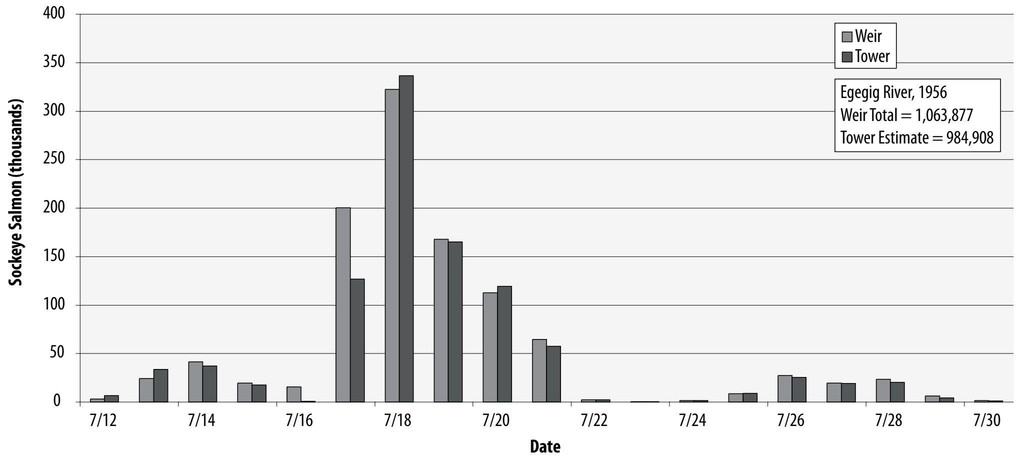


FIGURE 4. — Comparison of daily weir and systematic tower counts (30-min. counts/hour) for sockeye salmon escapement, Egegik River, Alaska, 1956. The relative error (i.e., [tower-weir]/weir) between methods was –7.4% (data from Reitz 1957).

FIGURE 5. — Sockeye salmon backed up behind a weir (Bear Creek, Tustumena Lake, Alaska).

In 1957, towers placed above a weir showed relative error of tower counts to be +12.9% (see Figure 6) (Spangler and Rietze 1958), but biologists noted the weir had not been "fish tight" on at least 6 d (see Table 2), meaning that fish dug under or found a hole in the weir and passed uncounted. Relative error between methods was likely lower than was reported by Spangler and Rietze (1958). These initial studies indicated that compared to weirs, systematic tower counts were both (a) relatively accurate and (b) did not interfere with fish migration.

TABLE 2. — Summary of daily sockeye salmon escapement data from weir counts and counting tower estimates, Naknek River, Alaska, 1957 (data from Spangler and Reitz 1957). Asterisks indicate days when weir was not "fish tight" (i.e., fish passed through uncounted). Note the relatively large differences occurring at the peak of the run, 8–10 July.

Date	Weir estimate	Tower estimate	Tower – Weir	Tower – Weir ÷ Weir × 100 *relative error*
Jun 29*	6,375	8,040	1,665	26.1
Jun 30	7,401	7,560	159	2.1
Jul 1	7,437	7,420	–17	–0.2
Jul 2	1,380	728	–652	–47.2

Date	Weir estimate	Tower estimate	Tower – Weir	Tower – Weir ÷ Weir × 100 *relative error*
Jul 3	9,831	7,604	–2,227	–22.6
Jul 4	3,704	4,336	632	17.1
Jul 5	6,350	5,284	–1,066	–16.8
Jul 6	13,777	12,896	–881	–6.4
Jul 7*	2,662	3,188	526	19.8
Jul 8	93,592	145,204	51,612	55.1
Jul 9	75,436	100,408	24,972	33.1
Jul 10	149,787	136,072	–13,715	–9.2
Jul 11	58,415	61,256	2,841	4.9
Jul 12	32,052	35,104	3,052	9.5
Jul 13*	17,072	20,708	3,636	21.3
Jul 14	21,079	16,600	–4,479	–21.2
Jul 15	19,659	22,032	2,373	12.1
Jul 16	5,943	9,324	3,381	56.9
Jul 17	16,563	16,788	225	1.4
Jul 18	22,411	28,268	5,857	26.1
Jul 19	8,916	9,160	244	2.7
Jul 20	6,203	7,544	1,341	21.6
Jul 21*	10,862	10,764	–98	–0.9
Jul 22*	8,693	9,352	659	7.6
Jul 23	4,242	5,208	966	22.8
Jul 24	6,228	5,536	–692	–11.1
Jul 25	4,887	5,072	185	3.8
Jul 26	2,536	2,712	176	6.9
Jul 27	1,633	1,880	247	15.1
Jul 28	856	1,152	296	34.6
Jul 29*	2,647	2,304	–343	–13.0
Jul 30	1,336	1,620	284	21.2
Jul 30	1,036	1,000	–36	–3.5
totals	631,001	712,124	–81,123	12.9

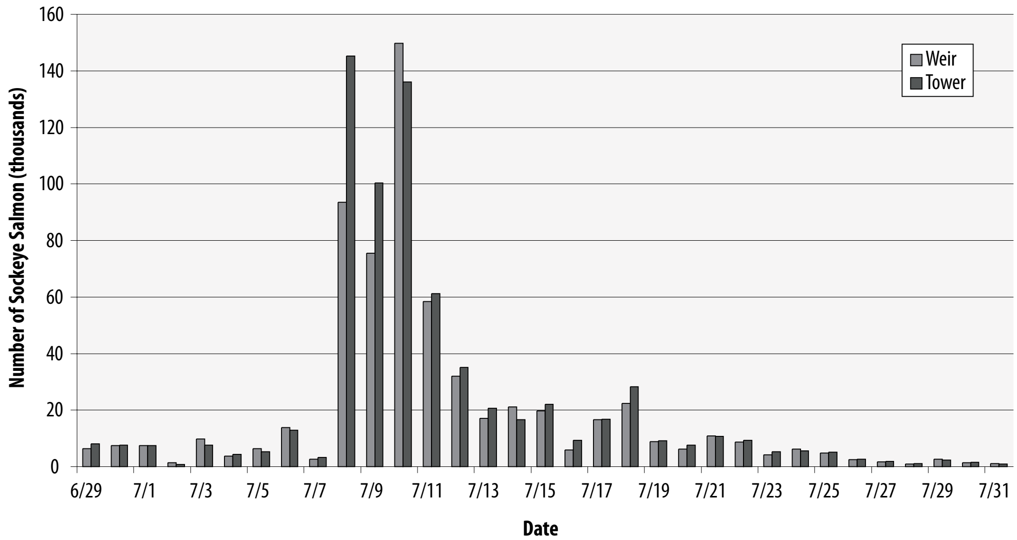


FIGURE 6. — Comparison of daily weir and systematic tower counts (15-min. counts/hr), Naknek River, Alaska, 1957. Relative error (i.e., [tower-weir]/weir) between methods was +12.9%; however, error may have been lower as the weir was not "fish tight" on 29 June, and 7, 13, 21, 22, and 29 July and fish passed through the weir undetected. The large discrepancy in estimates on 8 July suggests that the weir was not fish tight on that date either.

Because tower crews have other duties, such as seining salmon to collect biological samples (e.g., age, sex, length, and tissue for genetic analysis) from the upriver migrating population and because it is difficult for counters to maintain focus for long intervals, researchers sought to reduce sampling intervals without increasing relative error. Becker (1962) examined how counting interval length and sample frequency affected relative error of escapement estimates. Four systematic samples of 10, 20, 30, 40, and 60 min were taken from a continuous 48-h count at a frequency of 1–4 h. Short counts (<40 min) that were conducted every 1–2 h generally ranged within ± 6% of the actual count, whereas a wider range of error was observed for counts taken every 3–4 h (see Figure 7). Because error was not greatly reduced through longer sample intervals and because prior studies indicated relatively low relative error compared to weirs (Rietze 1957; Spangler and Rietze 1958; Becker 1962), the nonrandom systematic 10–20-min sample counts per hour, 24 h a day, were widely adopted. Interestingly, psychologists later conducted attention span studies on students and showed that they could only focus an average of 15–20 min before their attention lapsed (Johnstone and Percival 1976), providing further support for short counting intervals.

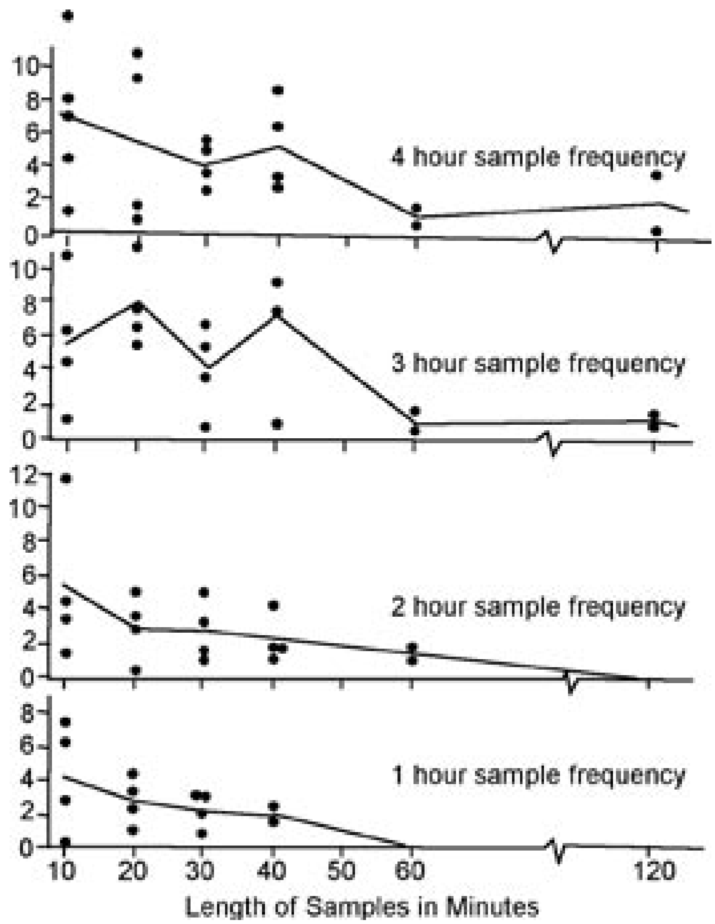


FIGURE 7. — Relationship between counting interval length, sample frequency, and relative error. Dots denote relative errors from different systematic samples from a 48-hour period; solid lines denote the mean relative error (i.e., [estimate – true total]/true total) for a given sampling interval duration. (Graph from Becker [1962].)

Siebel (1967) reevaluated systematic counting protocols for eight rivers in Alaska and found that relative errors ranged from –34.9% to +21.8% but were equally divided between over and underestimates, indicating a lack of bias. Mean relative error was 0.9%, insignificant at the 95% confidence level, with a reported 95% confidence interval of (–7.1%, 8.9%). He recommended sample count intervals be increased to 20 min if migration occurred in less than a week, if migration was highly concentrated, or if short-period escapement estimates were needed for calibrating aerial surveys.

Sources of error

Counting towers do not provide error-free estimates of escapement. The primary factors that affect accuracy and precision of counts are

- observer variability,
- aspects of migration,
- weather conditions, and
- systematic sampling method—nonreplicated versus replicated.

Observer variability

Variability among counting tower personnel in their ability to record data, detect and count fish, or identify species may introduce error in escapement estimates. Becker (1962) examined such error by conducting a series of 32 paired 5-min counts; one observer participated in all 32 counts while three rotated. The total difference between observers ranged from −5.3% to +3.5%; total counts differed by 1% implying that observer error was unbiased and therefore tended to cancel out (Becker 1962). A similar study used paired tower counts with both an inexperienced and an experienced observer over a range of conditions. Each paired test ($n = 3$) consisted of eighteen 10-min counts; six daylight, six crepuscular, and six night counts. Percent errors ranged from −1.8 to +1.3 and resulted in a combined total error of +0.4% (117 fish difference out of a total of 29,000 fish; see summary in Anderson 2000). These studies indicated that observer bias under a variety of conditions was random; when added together, overestimates (+) and underestimates (−) of fish passing the towers tended to cancel out. Observer bias should not be ignored; project leaders can reduce such bias by conducting paired counts with inexperienced personnel until they demonstrate count and species identification proficiency. Computerized training programs that teach estimation techniques are available; go to <www.wildlifecounts.com> for more information.

Aspects of migration

Within a given river system, species generally vary enough in the following traits to allow counters to distinguish among them: size, coloration, migration timing, and/or behavior (Groot and Margolis 1991). For example, in the Kvichak River in Alaska, sockeye salmon and chinook salmon *O. tshawytscha* may migrate by towers at a similar time, but sockeye salmon are much smaller—and hence easy to distinguish with little training. Even the smallest salmon (pink salmon *O. gorbuscha*) are relatively large compared to other fishes, weighing about 2–6 kg and easy to see from towers. Generally, not all species migrate at the exact same time, although in some rivers there can be considerable overlap, making tower counts alone infeasible (Dunmall 2004); in such cases, use of weirs or video monitoring should be considered. In many Alaskan systems, chinook salmon migrate first, followed by chum salmon *O. keta* and pink salmon, then sockeye salmon, and finally coho salmon *O. kisutch*. Many tower systems, such as those in Bristol Bay, oversee rivers that are dominated by sockeye salmon, and other species are relatively rare.

An extreme but rare example of the potential range in daily salmon escapements is from the Kvichak River in Alaska when, in 1980, a strike by fishermen led to a sockeye salmon escapement of 22.5 million fish (Anderson 2000). Daily escapement estimates ranged from 0 to 1.8 million salmon, with an estimated 0–150,000 fish passing the counting towers during every 10-min counting interval. In this situation, observers visually divided migrating bands of salmon into tens, hundreds, and even thousands, and tallied observations accordingly. The impact of this type of error has not been studied; however, Becker (1962) found a slight positive correlation between number of migrants and observer bias with greater variation observed when number of migrants equaled or exceeded 700 fish per 10-min interval. Examination of the data in figures 4 and 6 imply greater observer bias at high migration densities, but further research is clearly needed.

Weather conditions

Glare, overcast skies, high winds, rain, and turbidity all reduce visibility and affect count accuracy. While this source of error has not been quantified, it can be reduced through

1. careful site selection that reduces glare and wind in the counting region (in Figure 1, note wind direction and how the counting region in front of the tower is not turbulent);
2. use of polarized glasses to reduce glare and improve cloudy-day visibility.
3. use of riffle dampeners just upstream of the counting area, which can help reduce surface turbulence in the counting region (these structures are usually floating wood or logs in a V-shape); and
4. use of lighter substrates or panels (figures 2 and 7), which can help in spotting salmon.

Turbidity and associated decline in water clarity is usually uncontrollable, whether due to storm runoff or glacial water intrusion. There is little that can be done with regard to storm runoff, and fortunately the impact is temporary. Most projects use a form of count interpolation to account for missed sample intervals (see section on count interpolation). Glacial water intrusion is a different story. Determine if and when glacial water intrudes at the selected site relative to fish migration; then assess whether it will prevent accurate counts. If glacial water makes tower counts prohibitive, consider using hydroacoustic estimation techniques.

Systematic sampling method (nonreplicated versus replicated)

The sampling design selected can affect both variance of the total escapement estimate and bias in estimates of that variance. See the Sampling Design section on pages 371–374 for guidance.

Sampling design

Site selection

Generally, one tower is installed on each river bank, although up to four have been used on divided channels. During site selection you specifically select noncomplex reaches (e.g., no pools, no woody debris, level bottom) as you must have a clear view of the river in front of the tower, and fish must continually move upstream. The following list will help guide site selection.

1. Ensure that upstream migration of adult fish is in an observable pattern; it may be feasible to divert fish to an observable region with a partial weir (see Figure 8) or bright substrate panels.
2. Avoid sites where fish mill, spawn, or move downstream.
3. Ensure that you have generally clear water during the migration period.
4. Ensure that you have a constrained channel (i.e., not braided).
5. Ensure that the area is relatively protected from glare and prevailing wind; some projects employ alternative counting sites when specific weather conditions prevail.

6. Ensure that you have relatively laminar flow in the counting region throughout the migration period; because river flow changes throughout the season, it is important to examine flow patterns over a range of discharge to ensure that the counting region remains relatively free from turbulence.
7. Ensure that water depths are ~0.5–3 m where fish travel; again, let fish migration pattern and observability be your guide.
8. Ensure that bottom substrate contrasts with passing fish (see Figure 3) or allows installation of panels or other materials to achieve such contrast (see figures 2, 8, and 9).
9. Situate tower sites (ideally) directly across from each other; if fish do not cross from bank to bank in intervening river passage, tower sites may be somewhat staggered.
10. Install floodlights either above or across the entire river or on the shore near towers on night counts (see figures 1, 8, and 9); light system selection will depend on salmon behavior (e.g., are they migrating near shore or are they distributed across the entire river width?).

FIGURE 8. — Example of a diversion weir used in a counting tower project to guide fish into observable range. (Photo courtesy of the Alaska Dept. of Fish and Game.)

FIGURE 9. — Counting tower, contrast panels, and a riverwide suspended lighting system on the Chatanilka River, Alaska. (Photo courtesy of the Alaska Dept. of Fish and Game.)

Systematic sampling designs are the standard for using counting towers to estimate escapement of Pacific salmon in Alaska; however, there are many possible variants of systematic sampling (Reynolds et al., in press). All provide unbiased estimates of total escapement but differ in the variation of the total escapement estimate and the bias associated with estimates of that variation.

Nonreplicated systematic sample design

The most common sampling design for counting towers in Alaska is nonreplicated systematic sampling of 10 min per hour (see Table 4). Before the initiation of sampling, a random number is drawn from the range 1 to 6; each number represents a 10-minute count interval over a 1-h period. Counts are then made at the selected interval of each hour for the rest of the season. For example, say the first counter of the season randomly selects interval 2. She takes her first count at 12:10, her second at 13:10, her third at 14:10, and so forth. This design does not allow for unbiased estimation of the variance associated with the total escapement estimate. For estimating salmon escapement using nonreplicated systematic sampling designs, Reynolds et al. (in press) show that the best variance estimator is the V5 estimator of Wolter (1984), defined on page 376. Calculations are discussed in the statistical analysis section on pages 376–377.

TABLE 4. — Systematic sampling designs commonly used in estimating total sockeye salmon escapement from tower counts (see Becker 1962, Anderson 2000, and analysis by Reynolds et al. in press) (j = replicate index).

Design		Daily mean escapement, $\bar{y}$	Expansion[1]	Possible samples[2]
Nonreplicated systematic	20 min / 2 hr	$\sum_{i=1}^{n} y_i / n$	$6 \times 24 \times N$	6
	10 min / 1 hr	$\sum_{i=1}^{n} y_i / n$	$6 \times 24 \times N$	6

Design		Daily mean escapement, $\bar{y}$	Expansion[1]	Possible samples[2]
Replicated systematic	4 @ 10 min / 4 hr	$\sum_{j=1}^{4}\left(\sum_{i=1}^{n} y_{ij}/n\right)\Big/4$	24 × 24 × N	10,626
	2 @ 10 min / 2 hr	$\sum_{j=1}^{2}\left(\sum_{i=1}^{n} y_{ij}/n\right)\Big/2$	12 × 24 × N	66

NOTE: Total annual escapement is estimated by expanding the daily mean escapement: $\hat{Y}$ = (Expansion) × $\bar{y}$.

[1]Units/hr × hrs/day × days

[2]Number of possible samples given a sampling period of *N* consecutive days.

Replicated Systematic Sample Design

Replicated systematic sampling designs consist of multiple, independently selected nonreplicated systematic samples (Reynolds et al., in press). A replicated systematic sample of 2–10 min/2 h systematic samples is created by having the first counter of the year randomly draw two numbers ranging from 1 to 12; each number represents a 10-min count interval over a 2-h period. Counts are then made at the selected intervals for the rest of the season to generate two independent (replicated) systematic samples. For example, say the first counter of the season randomly selects intervals 2 and 10. She takes her first count at 12:10, her second at 13:30, her third at 14:10, her fifth at 15:30, and so forth. At the end of the season the counts from interval 2 (12:10, 14:10, etc.) and the counts from interval 10 (13:30, 15:30, etc.) are analyzed separately as nonreplicated systematic samples, each providing an estimate of total escapement. These estimates are analyzed for an overall escapement estimate and associated variance. This design provides unbiased estimates of both total escapement and its variance (Reynolds et al. in press). Calculations are discussed in the Statistical Analysis section on pages 378–380.

Nonreplicated versus replicated systematic sampling designs

A recent comparison of systematic sampling designs for counting towers for large (22 million) and small (2 million) salmon escapements demonstrated that nonreplicated systematic sampling produced estimates of the variance associated with the total escapement estimate that were biased high even with the best variance estimator, while replicated systematic sampling provided unbiased estimates (Reynolds et al., in press). Furthermore, the simulation study showed a 25% reduction in the average estimated variance, averaged across years of simulated high and low escapements, using a replicated design of four replicated systematic samples of 10 min/4 h compared with the standard nonreplicated 10 min/h design.

Field/Office Methods

Setup

Preseason tasks

1. The tower site should be selected in advance of the anticipated project to maximize efficiency and accuracy as well as to provide continuity across years. What seems like an ideal tower site relative to abiotic factors (e.g., water depth, substrate) may not be ideal relative to salmon behavior. The most important factor in selecting a site is that salmon pass the selected counting tower site in an observable pattern. A pilot season to check migration and flow patterns at peak and postpeak migration is advised.
2. The selected site must be able to support a 3–7-m tower, stabilization cables, and a field camp for at least three people. The field camp should be located above flood lines.
3. Evaluate your field site relative to your planned power source. For example, if you plan to use solar cells, make sure you are able to capture sufficient sunlight for your seasonal power needs.
4. Permits (as applicable): Obtain landowner (e.g., state, tribal, federal, private) permits well in advance of field season. Deadlines, requisites, and fees vary. Collecting age, sex, and length data may require a fish handling permit.
5. Prior to going into the field, order, assemble, and test critical counting tower and camp gear, such as scaffolds and anchors, solar panels, lights, camp stove, and water purifier. Bring extra parts and leave enough time to obtain any missing parts.
6. Advertise available positions and recruit personnel.

Events Sequence

Project leaders usually have a known time frame within which the salmon run of interest will occur. Events sequence varies, depending on what data are needed. For total escapement counts over the duration of the salmon migration, our field crews (consisting of 3 to 4 people each) arrive at the main office 1–2 weeks in advance of project mobilization to undergo safety training, get supplies, and pack. Crews and gear generally reach field sites via plane charter and/or boat. Once on the site, towers and light systems typically take a day or two to set up; counts generally begin on the second day. The first day of counts is from 08:00 to 17:00 hours. If no salmon are observed, the next shift begins the next day at 08:00. Once fish begin moving by the towers, crew members work 8-h shifts, 24 h a day. Tower counts stop once the fish stop migrating or when the daily estimated fish numbers drop below 1% of the total run size.

Data Handling, Analysis, and Reporting

Measurement details

Data collection

Data collection at most towers is relatively simple: Observers count fish as they move upstream past the tower. When fish densities are high, counters may use one click on their hand tally to indicate tens, hundreds, and (rarely) thousands of passing salmon. Downstream movement is tracked on a separate hand tally and subtracted from the daily escapement total prior to expansion. Again, downstream movement can be minimized or avoided by careful site selection.

Observers each keep a log of hourly counts and observations (e.g., date, initials, interval time, species counts for left and right banks, visibility comments [see Table 3]) in a waterproof field notebook; data are entered onto standard forms after each shift. Some projects are more complex, requiring observers to keep track of both upstream (+) and downstream (–) movement of fish and/or more than one species. Daily totals are called in to main offices each day, entered into an Excel spreadsheet, graphed, and distributed as needed to cooperators and stakeholders.

TABLE 3.—Water clarity rankings used at salmon counting towers by the Alaska Department of Fish and Game.

Rank	Description	Salmon Viewing	Water condition
1	Excellent	All passing fish observable	No turbidity or glare; all routes of passage observable
2	Good	All passing fish observable	Minimal to very low levels of turbidity or glare; all routes of passage observable
3	Fair	All passing fish observable	Low to moderate levels of turbidity or glare; all routes of passage observable
4	Poor	Some passing fish may be missed	Moderate to high turbidity or glare; some likely routes of passage obscured
5	Unobservable	Passing fish not observable	High turbidity or glare; all routes of passage obscured

Original data sheets are transferred to the main office regularly and are reviewed by the project leader. Any discrepancies between reported and original data are verified with observers to ensure accuracy.

Although it happens relatively rarely, high discharge, turbidity, or lack of access to the tower can be a problem. When it does happen, estimate the missed count with linear interpolation between counts prior to and after the event. If only one bank count was missed, estimate the missing count based on either the bank-to-bank relationship or by the time relationship for that bank, depending on which relationship is stronger.

Statistical analysis

Nonreplicated systematic samples: total escapement $\hat{Y}$

Total annual escapement is estimated by expanding the daily mean escapement:

$$\hat{Y}_{Nonrep} = (expansion) \times \bar{y} = (expansion) \times \sum_{i=1}^{n} y_j / n \qquad \text{(eq 1)}$$

where y_j is the count from the jth observation period, there were n total observations, and the *expansion* factor is (# of possible intervals per sample period) × (# of sample periods in a days) × (# of days in season) (Reynolds et al., in press). For example, for a 10-min/h systematic sample, the expansion factor is 6 × 24 × N, where there were N days in the season.

Nonreplicated systematic samples: variance of total escapement

The V5 estimator by Wolter (1984) is recommended for estimating variance of the total escapement estimate. It reduced uncertainty by 38–95% compared to other common variance estimators in a simulation study of systematic sampling for tower counts (Reynolds et al., in press). The estimator is based on sequential differences among observations:

$$V(\hat{Y}_{Nonrep}) = (1 - f)(1/n) \sum_{j=5}^{n} c_j^2 / (3.5(n - 4)) \qquad \text{(eq 2)}$$

where

$$c_j = y_j/2 - y_{j-1} + y_{j-2} - y_{j-3} + y_{j-4} / 2$$

where y_j is the count from the jth observation period, there were n total observations, and f is the proportion of the possible observations that were actually collected, $f = 1$ / (# of possible intervals per sample period).

Nonreplicated systematic samples: confidence intervals

Reynolds et al. (in press) examined four confidence interval estimators for both nonreplicated and replicated systematic samples and found that they were effectively identical in terms of both mean width and coverage. Here, the familiar normal interval is recommended:

$$\hat{Y}_{Nonrep} +/- 1.96 \sqrt{\hat{V}(\hat{Y}_{Nonrep})} \qquad \text{(eq 3)}$$

assuming

$$\hat{Y}_{Nonrep} \sim \text{Normal}(\hat{Y}_{Nonrep}, \hat{V}(\hat{Y}_{Nonrep}))$$

Replicated systematic samples: total escapement

Following the example earlier, assume the design provided two replicates, each a nonreplicated systematic sample of 10 min/2 h. One replicate observed the second interval of each period, the other the tenth interval. At the end of the season the counts from interval 2 (12:10, 14:10, etc.) and the counts from interval 10 (13:30, 15:30, etc.) are analyzed separately as nonreplicated systematic samples using the equations above, each providing an estimate of total escapement. The overall estimate of total escapement is the mean of the replicate estimates

$$\hat{Y}_{Nonrep} = (\hat{Y}_{Nonrep\,1} + \hat{Y}_{Nonrep\,2})/2 \qquad \text{(eq 4)}$$

Replicated systematic samples: variance of total escapement

The variance of the total escapement is estimated directly from the replicate total escapement estimates using the usual sample variance formula:

$$V(\hat{Y}_{Rep}) = \frac{1}{k-1}\sum_{i=1}^{k}(\hat{Y}_{Nonrep_i} - \hat{Y}_{Rep})^2 \quad \text{(eq 5)}$$

where *k* is the number of replicates (*k* = 2 in the example).

Replicated systematic samples: confidence intervals
The normal interval is recommended for confidence intervals, as it was for nonreplicated systematic samples.

Database design
An excellent example of database design used for salmon escapement is available from the Alaska Department of Fish and Game (ADF&G), Commercial Fishery Division for its Bristol Bay Management Area.

Data entry procedures
All data are field checked and verified by the project leader. In the main office original data (from observer forms) are entered into the database and proofed up to three times for accuracy. Proofreaders initial and date raw forms to indicate task completion. Data are backed up nightly onto the network by system administrators and individual project leaders.

Data summaries
Report formats vary with the agency conducting the escapement estimate. Our projects follow standard scientific reporting outlines (i.e., abstract or executive summary, introduction, methods, results, conclusions) with the addition of any recommendations and problems encountered (Woody 2004). Commercial fishery managers of the ADF&G include tables of daily escapement from all towers in its district as part of a much larger management report (ADF&G 1974–2000).

Archival procedures
Hard data are copied and archived with cooperating agencies; raw forms are stored by year in the main office of the collecting agency with a computer backup of the final database for that year. Electronic data are generally archived on the network hard drive, on the project leaders' hard drive, and on a DVD or similar storage device.

Personnel Requirements and Training

Tower crews generally consist of 3–4 technicians who conduct a daily 8-h shift and a project leader who ensures that crews are properly trained and that data are collected and recorded neatly and accurately.

Responsibilities
Project leaders are responsible for

1. selecting an appropriate counting tower site and conducting a pilot study;
2. obtaining appropriate permissions for camp establishment from landowners;
3. obtaining all appropriate state and federal sampling permits;

4. determining run timing of target species and mobilizing crew in a timely manner;
5. ensuring that towers are correctly installed and secured;
6. installing the electrical system and determining proper light angle and rheostat settings;
7. training field crews by
    a. ensuring that crews have all necessary safety training (e.g., first aid, CPR),
    b. training crews to be consistent and accurate in time and manner of counts (missed or late counts are undesirable and complicate error estimates),
    c. ensuring that crew members understand how the project fits into regional fishery management plans,
    d. conducting independent paired counts with inexperienced staff members for a minimum of 24–48 h over a range of conditions and fish densities, and
    e. ensuring that paired counts with experienced crew members should be made for 20 h over a range of fish densities.
8. periodically visiting each field crew to review accuracy of data collection, recording, and expansion practices;
9. assisting with counts during run peaks to assure quality control and accuracy; and
10. writing the annual report.

Technicians are responsible for

1. setting up and maintaining field camp,
2. learning to identify and enumerate the species of interest,
3. ensuring that the counts made during their 8-hour shift are conducted on time,
4. recording hourly counts in both field notebooks and on daily data sheets,
5. entering data into a computer and graphing results, and
6. calling in daily totals to fishery managers if necessary.

Qualifications

Compared to weirs, mark–recapture , and hydroacoustic projects, counting tower projects are relatively simple to implement. Project leaders should understand systematic sampling protocols, be able to install necessary electrical system (e.g., solar, turbine, generator), and have excellent troubleshooting and supervisory skills.

Field crew observers should be reliable, able to identify the species of interest, make simple mathematical calculations, safely pilot watercraft (if necessary), climb towers, and assist in field camp logistics and maintenance. Observers can generally develop needed skills on site. Because many counting tower projects are conducted in remote areas and require frequent boat travel, crew members should receive appropriate safety training.

It is recommended that field crews receive and pass tests for first aid, CPR, watercraft safety, bear behavior and safety, firearms safety, and proper lifting techniques. Having at least one crew member with watercraft troubleshooting skills is a valuable addition. Many counting tower projects successfully employ volunteers, entry-level technicians, retirees, teachers on summer break, and student interns. The best way to train a new field crew in systematic sampling protocols, fish identification, and data collection is to train them on site. Pairing experienced personnel with new crew members to ensure accurate and consistent data collection and entry is critical.

Budget Considerations

Estimated costs of a remote site counting tower system

Generally, there is a positive correlation between project cost and remoteness of the site. If observers must cross the river to make counts, two dependable boats are necessary; project leaders can determine which boat and motor combination is best suited to river conditions. The following estimates were valid in 2005. To save money on food shipments to remote locations, it may be more economical to shop for nonperishables well in advance and then mail or barge them to the nearest accessible town for later transport to the field site.

TABLE 4. — Cost estimate for establishing a remote counting tower field site, based on 2006 estimates obtained over the Web. Salary, permits, food, fuel, and transportation costs are not included, due to wide variation in cost among potential sites.

Item	Quantity	Cost per unit (USD)
Aluminum scaffolding and anchoring systems	1–4	$4,000–8,000
Solar panels, inverters, and charger accessories	2—one for each bank	$2,000–4,000
12 V deep-cycle marine batteries	4	$100–500
Lighting system for river and camp	Varies by project design	$100–2000
Field gear (e.g., tents, sleeping bags, stove, water system)	Per person	$1,000

Operational Requirements

Equipment needs

1. Enough counting towers to allow complete observation of the migration corridors. Aluminum scaffolding is most often used; however, high bluffs, trees, dams, and bridges can be surrogates.
2. Electronic timers with audible alarms to delineate shifts.
3. Polarized sunglasses; dark pairs for sunny days and lighter pairs for darker days.
4. Waterproof field notebooks and pencils for each observer to record his/her counts.
5. Hand tally counters.
6. Light system: night counts are integral to obtaining good abundance estimates at towers. Fish will avoid bright lights, but if the entire river is illuminated as allowed by the design illustrated in Figure 8, fish have no

choice but to pass through the beam. Rheostat controlled light beams (see Figure 1) may be used when it is not feasible or desirable to illuminate the entire river width. They can be used to either illuminate the fish passage zone or to divert fish closer to shore, where they are more visible.

7. If the site is remote, two boats are recommended for safety; if one is disabled, the other can be employed; fuel and oil for field season, tool kits, and troubleshooting guides are also essential.
8. If there is no electricity to the site, solar panels, generators, or turbine power can be used as energy sources. (We use solar panels to charge four deep-cycle marine batteries from which we run tower and office lights.)
9. If it is difficult to distinguish fish from the background, a contrasting panel or lighter substrate is necessary. A color similar to the bottom will provide contrast but not frighten fish. Materials used to improve contrast range from plastic sheets to metal panels anchored to the bottom. Experimentation will reveal the best substrate for your site.

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