U.S. Fish & Wildlife Service

Coho Salmon Population Assessment in Streams on the Pacific Ocean Side of the Alaska Peninsula, Alaska Peninsula National Wildlife Refuge, 2006

Alaska Fisheries Technical Report Number 95

King Salmon Fish and Wildlife Field Office
King Salmon, Alaska
January 2007

The Alaska Region Fisheries Program of the U.S. Fish and Wildlife Service conducts fisheries monitoring and population assessment studies throughout many areas of Alaska. Dedicated professional staff located in Anchorage, Juneau, Fairbanks, Kenai, and King Salmon Fish and Wildlife Offices and the Anchorage Conservation Genetics Laboratory serve as the core of the Program's fisheries management study efforts. Administrative and technical support is provided by staff in the Anchorage Regional Office. Our program works closely with the Alaska Department of Fish and Game and other partners to conserve and restore Alaska's fish populations and aquatic habitats. Additional information about the Fisheries Program and work conducted by our field offices can be obtained at:

http://alaska.fws.gov/fisheries/index.htm

The Alaska Region Fisheries Program reports its study findings through two regional publication series. The **Alaska Fisheries Data Series** was established to provide timely dissemination of data to local managers and for inclusion in agency databases. The **Alaska Fisheries Technical Reports** publishes scientific findings from single and multi-year studies that have undergone more extensive peer review and statistical testing. Additionally, some study results are published in a variety of professional fisheries journals.

Alaska Fisheries Technical Report Number 95, January, 2007
U. S. Fish and Wildlife Service

Coho Salmon Population Assessment in Streams on the Pacific Ocean Side of the Alaska Peninsula, Alaska Peninsula National Wildlife Refuge, 2006

Jeffry L. Anderson

Abstract

In 2006, the King Salmon Fish and Wildlife Field Office continued to develop and evaluate methods for using juvenile coho salmon *Oncorhynchus kisutch* abundance and density to monitor populations on the Pacific Ocean side of the Alaska Peninsula. Harsh weather conditions make monitoring adult coho salmon abundance extremely difficult. In 2006, we attempted to estimate potential coho salmon smolt capacity and adult production for Pass and Des Moines creeks in Wide Bay, about 150 km south of King Salmon, Alaska. Smolt production models and estimates of juvenile coho salmon densities in pool habitat were used to determine if the streams are at or near carrying capacity. Smolt capacity models indicate that about 1,000 adults are necessary to fully seed available habitat in Pass Creek. However, juvenile coho salmon densities in Pass and Des Moines creeks were extremely low, indicating that these streams were well below the predicted juvenile carrying capacity. Pass and Des Moines creeks are higher gradient, riffle-dominated systems in relatively narrow mountain valleys, whereas other streams where we have conducted similar analyses have been low gradient meandering channels on wide, well developed flood plains. Over-estimating the carrying capacity for Pass Creek is probably the result of stream gradient not being factored into the model. We recommend restricting the use of the current model to known productive systems until it can be refined for use in all stream types. We also recommend using aerial surveys to monitor coho salmon populations until a project can be completed to validate habitat model parameters including smolt production, overwinter survival, and smolt-to-adult survival for streams on the Alaska Peninsula.

Introduction

The Alaska National Interest Lands Conservation Act (ANILCA) specifically mandates that fish populations and their habitats be conserved in their natural diversity within the Alaska Peninsula/Becharof National Wildlife Refuge complex (Refuge; USFWS 1994). The conservation of adult Pacific salmon *Oncorhynchus spp.* stocks and resident species that are targeted in commercial, subsistence, or sport fisheries requires accurate monitoring of affected populations. Although benefits to subsistence, sport, and commercial users are maximized when fish populations are healthy, information on the fisheries resources on the Pacific Ocean side of the Refuge is lacking for many drainages, increasing the likelihood of overexploitation (USFWS 1994). In addition to human uses, large numbers of adult salmon are consumed by brown bears *Ursus arctos* (Burgner 1991; Heard 1991; Ruggerone et al. 2000; Quinn et al. 2003), other large predators (Darimont et al. 2003; Dombeck et al. 1984), and terrestrial vertebrates (Burgner 1991; Heard 1991). Salmon carcasses are also important for numerous invertebrate and fungi species including scavengers and decomposers that are necessary for nutrient cycling, which maintains healthy aquatic habitats and ecosystems (Cederholm et al. 1999; Jauquet et al. 2003). Juvenile salmon are an important food source for fish, birds, and small mammals (Burgner 1991; Heard 1991; Sandercock 1991).

Author: Jeffry L. Anderson is a fishery biologist with the U. S. Fish and Wildlife Service. He can be contacted at King Salmon Fish and Wildlife Field Office, P.O. Box 277, King Salmon, AK 99613; or jeffry_anderson@fws.gov.

Coho salmon *O. kisutch* spawn and rear in many Refuge streams on the Pacific Ocean side of the Alaska Peninsula. Although their distribution is widespread, most spawning populations are relatively small and occur in short (3 to 20 km) streams. With few exceptions, these runs are assumed to be stable and self-sustaining. This assumption is based on the availability of suitable freshwater habitat and not on escapement estimates, as limited data exist for coho salmon populations on the Alaska Peninsula. Coho salmon are opportunistic and can spawn in a wide variety of freshwater habitats ranging from moderate sized rivers to small headwater tributary streams (Sandercock 1991).

Coho salmon populations in Alaska are generally small, isolated from nearby populations, and genetically distinct (Olsen et al. 2003). Because genetic population structure of coho salmon occurs on a fine geographic scale, individual populations are more susceptible to extirpation, and the loss of individual populations can reduce overall genetic variability (Olsen et al. 2003). These factors justify managing and conserving coho salmon at a fine geographic scale. Coho salmon on the Alaska Peninsula are genetically distinct from other geographic areas in Alaska (Olsen et al. 2003); however, no analyses have been completed defining population structure within the Alaska Peninsula region.

Coho salmon are targeted in several commercial, sport, and subsistence fisheries along the Alaska Peninsula. The commercial fishery for coho salmon occurs along the entire southern portion of the Alaska Peninsula, with management jurisdiction allocated to three distinct areas within the Westward Region of the Alaska Department of Fish and Game (ADFG). The Alaska Peninsula Management Area encompasses all waters from Ugamak Island to Kupreanof Point; the Chignik Management Area encompasses all waters from Kupreanof Point to Kilokak Rocks; the Kodiak Management Area extends from Kilokak Rocks to Cape Douglas (Nelson and Lloyd 2001). Annual commercial harvest of coho salmon destined for streams on the Pacific Ocean side of the Alaska Peninsula can exceed 800,000 fish (Shaul and Dinnocenzo 2002; Brennan et al. 2005; Pappas et al. 2005). Although some professional fishing guides also target coho salmon in localized sport fisheries, the area is remote and difficult to access and harvest is probably minimal. No directed monitoring of coho salmon sport fishing occurs on the Pacific Ocean side of the Alaska Peninsula (Schwarz 1997). Coho salmon are also an important subsistence resource for many communities on the Alaska Peninsula (ADFG 2002), and harvest is typically concentrated in streams and rivers that are accessible to local residents. Monitoring of coho salmon subsistence harvest occurs through annual harvest reports completed by local residents.

Some coho salmon escapement monitoring on the Alaska Peninsula has been accomplished by the ADFG and the King Salmon Fish and Wildlife Field Office (KSFO). The ADFG monitors coho salmon escapement in the Chignik Management Area until early September as part of their normal operation using aerial surveys, but discontinues monitoring prior to peak migrations (Pappas et al. 2005). The KSFO used aerial surveys to monitor coho salmon escapement on numerous streams in 1994, and used a weir and walking surveys to monitor escapement on a single stream in 1995 and 1996 (Hetrick and Nemeth 2003) and again in 2002 and 2003 (Anderson and Hetrick 2004). The KSFO also used walking surveys to estimate escapement in streams near Perryville in 2002 and 2003 (Anderson and Hetrick 2004), and has used aerial surveys to monitor coho salmon runs near Chignik and Perryville since 2003 (Anderson 2006). However, none of these escapement monitoring efforts have been completely successful.

Monitoring adult coho salmon escapement in streams on the Pacific Ocean side of the Alaska Peninsula is difficult because of remoteness and bad weather. Coho salmon migrate into freshwater starting in late August, and runs continue well into November (Hetrick and Nemeth 2003; Anderson and Hetrick 2004). Also, coho salmon often move into smaller tributary streams to spawn with the onset of fall rains and increased flows (Meehan and Bjornn 1991; Sandercock 1991; Irvine et al. 1992). During these freshets, counts using visual surveys can be incomplete due to poor visibility and access (Hetrick and Nemeth 2003; Anderson and Hetrick 2004; Anderson 2004; Anderson 2006). Counts using fish weirs can also be incomplete during fall freshets as weirs can be inundated and overtopped by high water, often coinciding with times of peak migration (Whitton 2003; Anderson and Hetrick 2004; Anderson et al. 2004; Anderson 2005).

Because of the difficulty associated with monitoring adult coho salmon escapement, the KSFO has investigated other methods to monitor individual populations on the Alaska Peninsula, including application of techniques developed to predict coho salmon freshwater production capacity for Oregon (Nickelson et al. 1992; Nickelson 1998) and other Pacific Northwest (Bradford et al. 1997) streams. In 2002 and 2003, we used a habitat limiting factor model (Nickelson 1998) to identify factors limiting smolt production and to estimate potential adult coho salmon production based on seasonal carrying capacities of juvenile coho salmon (Anderson and Hetrick 2004). This model is based on the assumption that when a specific habitat is in short supply, a bottleneck exists that may subject a cohort to density-dependent mortality, which may lead to an under-seeding of habitats used by subsequent life stages. Estimates of available surface area by habitat type were identified in a stream habitat inventory and used as the primary input to the Nickelson (1998) model. A model developed by Bradford et al. (1997) was also used to predict average abundance of coho salmon smolt based on stream length. The Nickelson (1998) and Bradford et al. (1997) models both yielded similar estimates of smolt production, and Anderson and Hetrick (2004) found that the model of Bradford et al. (1997) closely approximated smolt production estimated from the intensive habitat inventory model (Nickelson 1998) for streams on the Alaska Peninsula, except where large amounts of off-channel rearing habitat (i.e., large ponds) were present.

Based on the work accomplished in 2002 and 2003, KSFO is currently investigating techniques using remote sensing, life-history based smolt production models, and juvenile abundance as a surrogate for adult numbers to monitor coho salmon populations in streams on the Pacific Ocean side of the Alaska Peninsula. Assessing coho salmon populations by monitoring juvenile abundance during summer months has the potential to be more effective based on access, weather conditions, and cost compared to monitoring adult escapement in the fall for streams on the Alaska Peninsula. In 2006, KSFO planned to estimate juvenile coho salmon freshwater carrying capacity and potential adult production for streams in Wide Bay on the Alaska Peninsula and determine if those systems are at or near carrying capacity. The objectives of the work in 2006 were to:

1. Estimate potential coho salmon smolt capacity and adult production for streams in Wide Bay using smolt production models;

2. Estimate juvenile coho salmon densities in pool habitat in study streams to determine if they are at or near carrying capacity;

3. Estimate minimum numbers of coho salmon returning to streams in Wide Bay; and

4. Determine if any study streams require further monitoring based on juvenile and adult observed and modeled production capacity.

We view the work in 2006 as the next step in the development and validation of habitat-based smolt production models, further validation of summer parr densities used in the Nickelson (1998) model, and a validation of juvenile sampling techniques for streams on the Pacific Ocean side of the Alaska Peninsula.

Study Area

Wide Bay study streams are on the Pacific Ocean side of the Alaska Peninsula, and are within the Ugashik Unit of the Alaska Peninsula National Wildlife Refuge (Figure 1). The Wide Bay study area was selected for monitoring based on presence of coho salmon populations, proximity to King Salmon (146 km), and access via wheeled aircraft. Study streams include Short Creek, Pass Creek (Figure 2), Des Moines Creek (Figure 3), and Big Creek (Figure 4). Kialagvik Creek, Alai Creek, and the unnamed tributary between Alai Creek and Short Creek are not accessible with wheeled aircraft, and were not scheduled for sampling. Coho, pink *O. gorbuscha*, and chum *O. keta* salmon, and Dolly Varden *Salvelinus malma* are present in Wide Bay streams. Based on previous sampling by ADFG and KSFO, coho salmon are known to be present in Big Creek, Des Moines Creek, Pass Creek, and Kialagvik Creek (Table 1). Although the presence of coho salmon in Alai and Short creeks and the unnamed stream between them has not been documented, sampling in the area has been minimal.

Wide Bay is located within the Mainland District of the Kodiak Management Area for ADFG commercial fishery management. The Mainland District includes all waters adjacent to the coastline of the Alaska Peninsula from Kilokak Rock to Cape Douglas, and up to 300,000 sockeye *O. nerka*, 500,000 pink, 200,000 chum, and 20,000 coho salmon are harvested in the district each year (Brennan et al. 2005). Although at least 27 streams in the Mainland District are believed to support coho salmon populations (Dinnocenzo 2006), no escapement goals for coho salmon have been established for the district (Nelson and Lloyd 2001).

Methods

The initial sampling plan for Wide Bay streams is presented in Table 2. Due to logistics, weather conditions, and the presence of spawning pink salmon, not all planned work was accomplished in 2006.

Habitat Inventory

Methods used to classify habitat types were modified from Hankin and Reeves (1988), Bisson et al. (1982), Overton et al. (1997), and Nickelson et al. (1992) and were similar to those used by Anderson and Hetrick (2004) for Alaska Peninsula streams. The habitat type classifications of Nickelson et al. (1992) were used for later compatibility with the habitat limiting factor model analysis. Habitats were classified as cascades, rapids, riffles, glides, trench pools, plunge pools, scour pools, dammed pools, backwater pools, alcoves, or beaver ponds.

The habitat inventory in Pass Creek was conducted by beginning at the mouth above the area of tidal influence and working upstream until a barrier to adult coho salmon upstream migration was reached. Tributary streams were surveyed beginning at the confluence with mainstem Pass Creek and working upstream until a barrier to adult coho salmon upstream migration was reached, or a terminal spring source was encountered. Individual habitat units were classified based on habitat type, length and width were measured, and amount of available spawning habitat was estimated. Length was measured along the thalweg. At least three wetted width measurements were made perpendicular to the thalweg and a mean width was calculated.

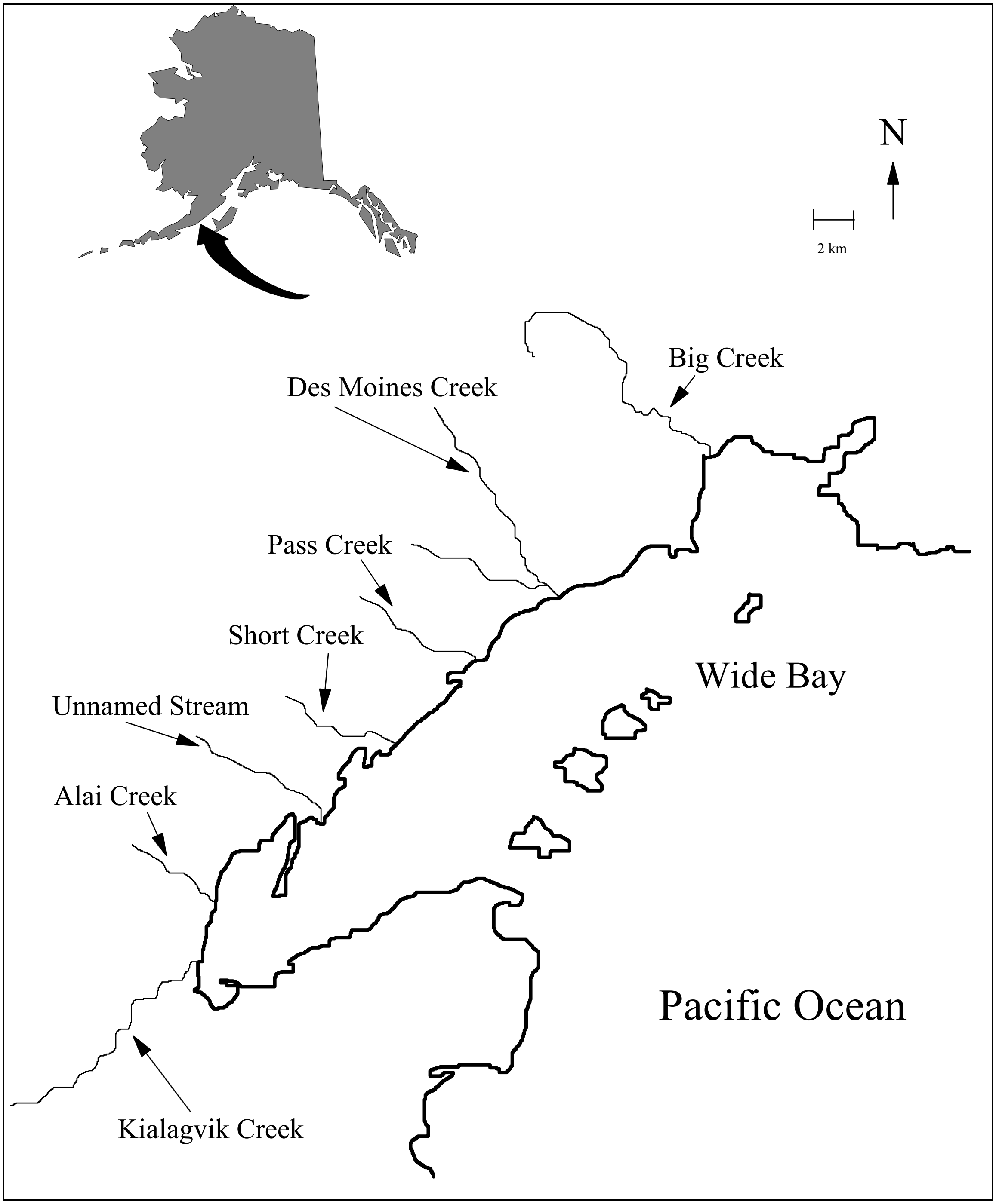

Figure 1. Wide Bay study area, Alaska Peninsula National Wildlife Refuge.

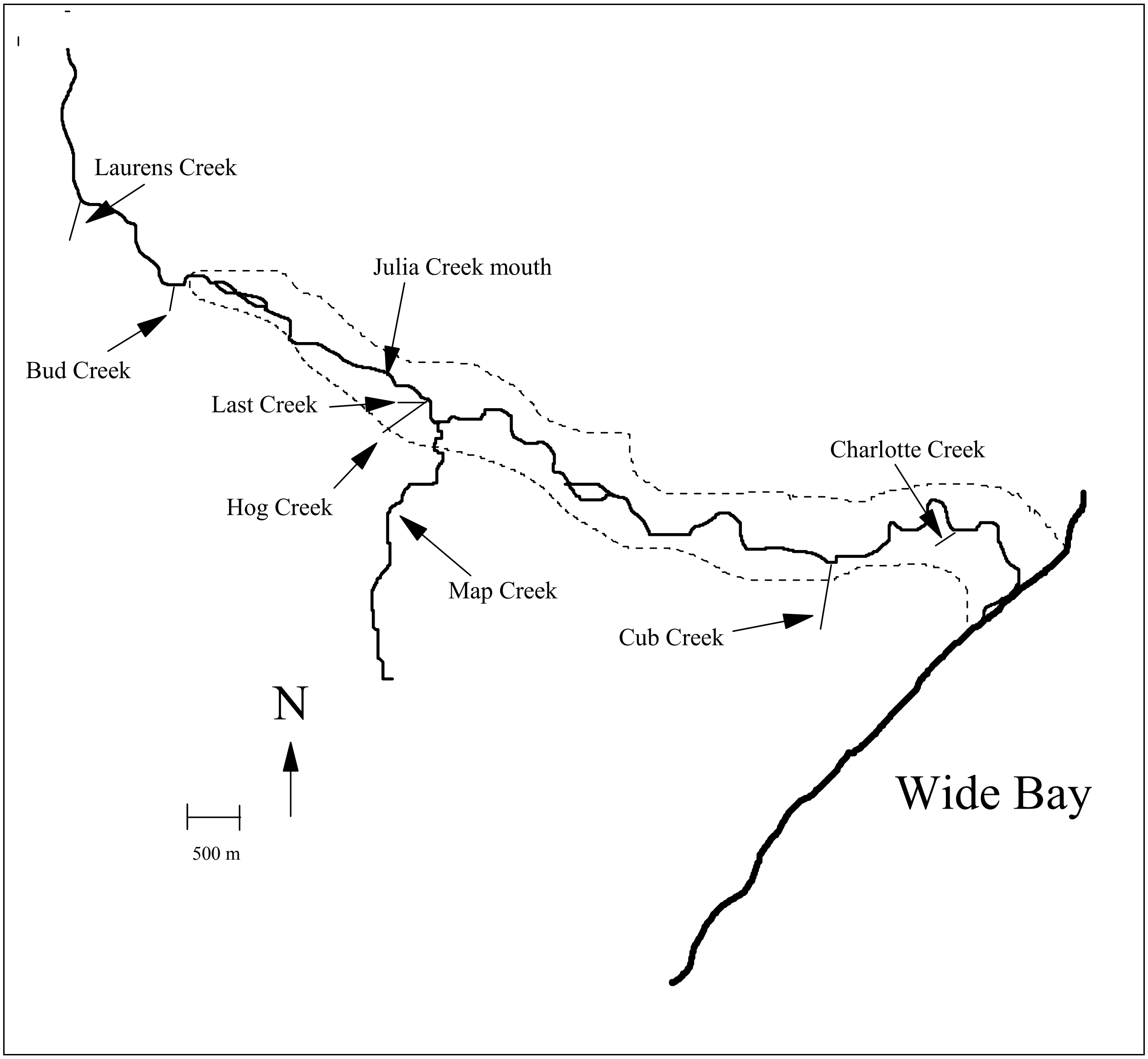

Figure 2. Map of Pass Creek in the Wide Bay study area. The dashed line represents the approximate extent of the developed floodplain estimated from topographic contours. Except for Map Creek, all tributary streams are depicted as straight lines based on GPS coordinates and do not represent actual sinuosity.

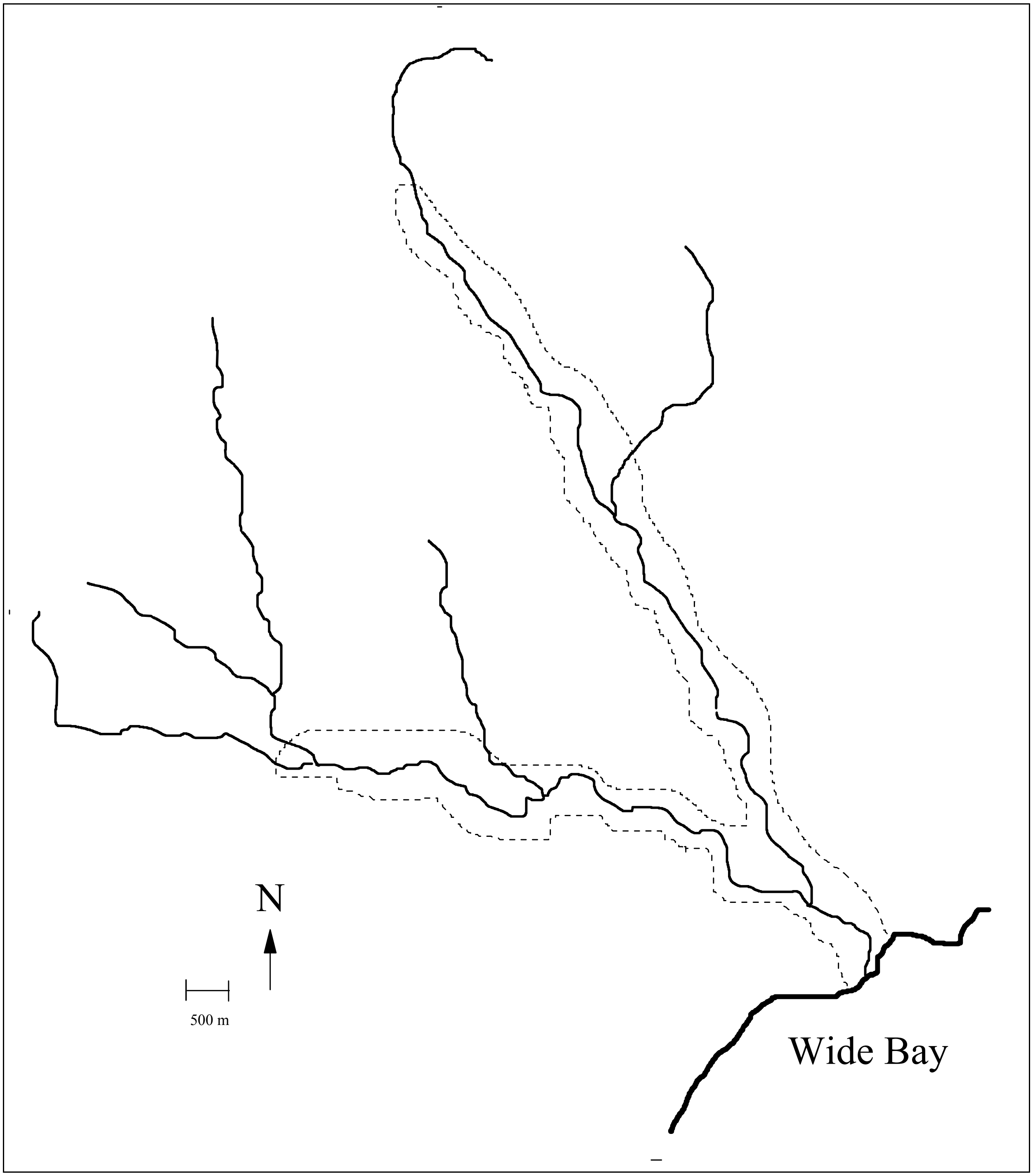

Figure 3. Map of Des Moines Creek in the Wide Bay study area. The dashed line represents the approximate extent of the developed floodplain estimated from topographic contours.

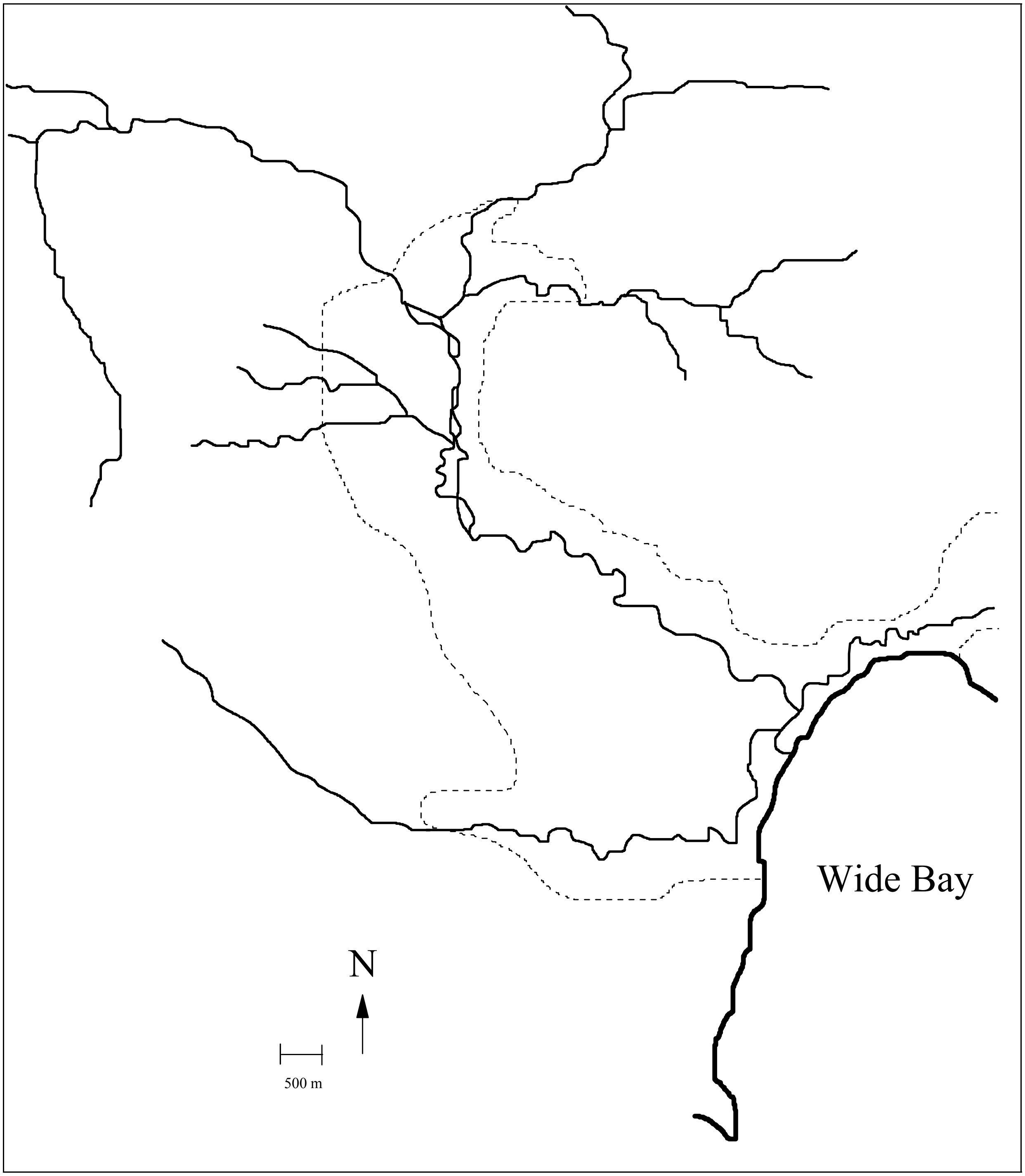

Figure 4. Map of Big Creek in the Wide Bay study area. The dashed line represents the approximate extent of the developed floodplain estimated from topographic contours.

Table 1. Presence of Pacific salmon in Wide Bay streams. PK = pink salmon; CM = chum salmon; CO = coho salmon; NS = not surveyed.

Stream	ADFG Stream Number[a]	ADFG Database[a]	KSFO Aerial Surveys[b]	ADFG Aerial Surveys[c]
Big Creek	262-85-10010	PK, CM, CO	CO	CO
Des Moines Creek	262-85-10020	PK, CM, CO	CO	CO
Pass Creek	262-85-10030	PK, CM, CO	CO	CO
Short Creek	262-85-10040	PK, CM	--	NS
Unnamed stream	262-85-10045	PK, CM	NS	NS
Alai Creek	262-85-10070	PK, CM	--	NS
Kialagvik Creek	262-85-10080	PK, CM, CO	CO	NS

[a] Johnson and Weiss (2006)
[b] Hetrick and Nemeth (2003)
[c] ADFG unpublished data

Table 2. Sampling planned and completed for streams in Wide Bay during summer 2006. Y = yes; N = no.

	Snorkel Survey		Mark-Recapture		Habitat Inventory	
Stream	Planned	Completed	Planned	Completed	Planned	Completed
Big Creek	Y	N	Y	N	Y	N
Des Moines Creek	Y	N[a]	Y	N	N	--
Pass Creek	Y	N[a]	Y	N	Y	Y
Short Creek	Y	N	N	--	N	--
Unnamed stream	N	--	N	--	N	--
Alai Creek	N	--	N	--	N	--
Kialagvik Creek[a]	N	--	N	--	N	--

[a] Desired sample size was not achieved.

Surface area of each habitat unit was calculated by multiplying the measured length of the unit by its mean width. Amount (percent) of spawning habitat was estimated based on visual observation of areas of suitable depth, velocity, and substrate available within each habitat unit. Suitable depth (between 0.15 and 1.0 m), velocity (between 0.30 and 1.0 m/s), and substrate (gravel and small cobble with limited surface fines) were categorized from Sandercock (1991). Surface area by habitat type and available spawning area were summed for mainstem Pass Creek and its tributaries for use in the habitat limiting factor analysis.

Juvenile sampling

Snorkel surveys were used to estimate juvenile coho salmon densities in pool habitat to determine if streams were at or near carrying capacity. Mark-recapture experiments were used to investigate the magnitude of bias associated with the snorkel surveys. Juvenile coho salmon densities were estimated in pool habitat in Pass Creek and Des Moines Creek; counts were conducted during periods of low flow in July and August, 2006. Surveys were performed in discrete pool habitat units using standardized underwater observation techniques and were conducted when the minimum depth, visibility, and water temperature criteria of Dolloff et al. (1996) were met or exceeded. Fish were counted by two observers as they moved slowly upstream through the habitat unit. Divers counted fish only in their prescribed lanes and did not count fish that moved among lanes to avoid double-counting (Dolloff et al. 1996). All fish observed were identified to species and counted; water temperature and underwater visibility were also measured at each site. Juvenile coho salmon densities (number of fish/m^2; X_i) at each site were calculated by dividing the number of fish observed by the surface area of the site. Mean juvenile coho salmon density in pool habitat for each stream ($\overline{X}$) was estimated as

$$\overline{X} = \frac{\sum X_i}{n}.$$

A sample size of 18 for snorkel surveys was chosen for each stream to test the hypothesis that juvenile coho salmon mean densities are at or above carrying capacity (H_o: $\overline{X} \geq 1.0$) following Zar (1996) as

$$n = \frac{s^2}{\delta^2}\left(t_{\alpha(1),\nu} + t_{\beta(1),\nu}\right)^2,$$

where $s^2 = 0.09$ from snorkel surveys conducted for juvenile coho salmon on the Alaska Peninsula (Anderson and Hetrick 2004), $\delta = 0.2$, $\alpha = 0.10$, and $\beta = 0.10$. A mean summer density of 1.0 fish/m^2 in pool habitat is a level believed to represent fully seeded habitat for juvenile coho salmon in coastal Oregon streams (Nickelson et al. 1992).

Sample sites were chosen for snorkel surveys using systematic sampling with a random start (Hankin and Reeves 1988), and the interval was determined based on the number of pools observed during the habitat survey; every 10th pool was selected for sampling in Pass Creek. Because the habitat survey was not completed on Des Moines Creek, every 10th pool was selected for sampling based on geomorphic similarities to Pass Creek. Only mainstem pools were selected for snorkel surveys in Pass Creek; twelve pools were selected for surveys in mainstem Des Moines Creek, and six were selected for surveys in the major tributary to Des Moines Creek.

Mark-recapture experiments were developed using baited minnow traps for the marking event and multi-pass electrofishing for the recapture event (Table 2); only one experiment was attempted on Pass Creek. Nets (3.2-mm mesh) were placed above and below the selected pool, anchored to the substrate using large rocks, and the tops of the nets tied off to nearby vegetation. Divers inspected the nets to verify closure and then completed a snorkel count in the pool as described above. Minnow traps (n = 12) baited with locally-collected salmon eggs were then set to capture fish for the marking event. However, within the first hour of fishing the traps, the upstream and downstream block nets became submerged due to the velocity of the water and the accumulation of small leaves and debris on the nets, even though the crew was on-site cleaning the nets. Juvenile coho salmon and Dolly Varden were observed swimming over the downstream block net when it became submerged. Because it was unlikely that block nets would have maintained closure for the mark-recapture experiments at other sites in Pass Creek or Des Moines Creek, especially over the planned 24 hr period, no further mark-recapture experiments were attempted.

Minimum Escapement Estimates

We initially planned on completing two aerial surveys to count adult coho salmon in Wide Bay streams using low-level helicopter flights. However, because we were unable to complete the juvenile and habitat sampling in most streams, we did not complete the adult monitoring during 2006.

Carrying Capacity Estimates

We used the habitat limiting factor model of Nickelson (1998; hereafter referred to as the habitat model) to identify factors that could be limiting smolt production, and to estimate carrying capacities for juvenile coho salmon in Pass Creek. The habitat model uses estimates of available surface area for each habitat type identified during the inventory. Habitat-type specific potential juvenile coho salmon rearing densities over three seasons (spring, summer, and winter; Table 3) were used to estimate seasonal production potential, and estimated available spawning habitat was used to estimate potential egg production. Density-independent survival rates (Table 4) were applied to potential seasonal carrying capacity estimates to generate potential smolt production estimates for each season. The specific life-stage that limits smolt production in the system is the life-stage capable of producing the fewest number of smolt.

Once an estimate of smolt capacity was obtained from the habitat model, back-calculations were used to determine the number of adult coho salmon needed to fully seed available habitat and to estimate potential production. The following equations and constants of Nickelson (1998) were used in the analysis. Potential smolt density (C, fish/m^2) was calculated as

$$C = \frac{M}{SA},$$

where M is the maximum smolt capacity from the habitat model and SA is the total surface area measured in m^2. Survival to the smolt stage (S_{smolt}) was calculated as

$$S_{smolt} = S_{egg} * S_{ow},$$

Table 3. Seasonal juvenile coho salmon potential densities (fish/m^2) by habitat type used in the habitat limiting factor model of Nickelson (1998).

Habitat Type	Spring	Summer	Winter
Cascade	0.00	0.24	0.00
Rapid	0.60	0.14	0.01
Riffle	1.20	0.12	0.01
Glide	1.81	0.77	0.12
Trench Pool	0.99	1.79	0.15
Plunge Pool	0.84	1.51	0.28
Scour Pool	1.29	1.74	0.35
Dammed Pool	2.56	1.84	0.56
Alcove	5.75	0.92	1.84
Beaver Pond	2.56	1.84	1.84
Backwater	5.75	1.18	0.58

Table 4. Density-independent survival rates (survival to smolt) from specific life stages used by the habitat limiting factor model of Nickelson (1998).

Life stage	Survival rate to smolt
Egg	0.32
Spring fry	0.46
Summer parr	0.72
Winter pre-smolt	0.90

where S_{egg} is a constant egg-to-summer parr survival rate of 0.072, and overwinter survival (S_{ow}) was calculated as

$$S_{ow} = 0.1361 * \log_e C + 0.487 + E,$$

where E is an error term. The egg deposition (D_M) needed to produce the maximum smolt capacity (M) was then calculated as

$$D_M = \frac{M}{S_{smolt}}.$$

The minimum number of spawners necessary to produce the required egg deposition (A_M) was calculated as

$$A_M = \left(\frac{D_M}{2{,}500}\right) * 2,$$

which assumes a 1:1 sex ratio (Anderson and Hetrick 2004) and 2,500 eggs per female (Nickelson 1998). The potential adult production (PP_x) of the system was then determined as

$$PP_x = M * x,$$

where x represents the marine survival rate. Following Nickelson (1998), three different marine survival rates ($x = 0.03$, 0.05, and 0.10) were used. Although Nickelson et al. (1992) recommend measuring and using total surface areas by habitat type for each season in the habitat model, we were only able to measure summer habitat due to the difficulty and expense of working in this area year round. We assume that if summer densities of juvenile coho salmon measured in Wide Bay streams are similar to those reported by Nickelson et al. (1992), we can use potential spring and winter juvenile densities in the habitat model (Table 3) applied to available summer habitat to produce reasonable estimates of smolt production for these streams.

The model of Bradford et al. (1997) was also used to estimate mean coho salmon smolt abundance (Y) based on stream length (X, km) for selected streams in Wide Bay as

$$Log_e(Y) = 6.90 + 0.97 Log_e(X).$$

A marine survival rate of 5% was applied to the smolt estimates (Y) to estimate adult production. Stream length was measured from U.S. Geological Survey 1:63,360 scale digital line graphs (DLG) for selected Wide Bay streams. We used the stream length measured during the habitat inventory for Pass Creek.

Results

Frequent heavy rain events limited the number of days we were able to complete field work in Wide Bay in 2006 (Appendix A). Work was not accomplished on over half of the available days, mostly because of weather. Rain events caused the streams to rise rapidly and become turbid, and it usually took 3 d for the streams to return to clear water base-flow conditions. Both Pass and Des Moines creeks were impacted to a similar extent by the rain events. The project start was also delayed for two days due to inclement weather.

Habitat Inventory

Over 26 km of stream were inventoried in the Pass Creek watershed during 2006, which included mainstem Pass Creek and eight small tributary streams (Table 5). Riffles and scour pools were the predominant habitat types observed; no beaver pond, dam pools, or trench pools, and few alcoves and plunge pools were observed during the inventory (Table 6). Over 13% of the surface area was estimated to be suitable spawning habitat, with scour pool tails accounting for over half of available spawning habitat (Table 6). Relatively small amounts of riffle habitat were judged to be suitable for coho salmon spawning, mainly due to fast water velocities. The habitat inventory was not completed on Big Creek as planned (Table 2) because of time constraints.

Juvenile sampling

Limited juvenile sampling was completed in Wide Bay in 2006. Only five snorkel surveys were performed on Pass Creek and Des Moines Creek, and only one mark-recapture experiment was attempted on Pass Creek; no juvenile sampling was completed on Big Creek or Short Creek as planned (Table 2). Juvenile coho salmon and Dolly Varden were the only species observed during snorkel surveys in 2006, and few juvenile coho salmon were observed in any of the scour pools sampled in either stream (Table 7). Because we could not calibrate the snorkel estimates with mark-recapture experiments, juvenile density estimates in Pass and Des Moines creeks should be considered an index of relative abundance. After about 1 August, underwater visibility was marginal (around 2 m) due to the presence of spawning pink salmon, and the high density of adult pink salmon in most pools after about 5 August prevented us from completing snorkel surveys.

During the unsuccessful mark-recapture experiment in Pass Creek, less than 10 coho salmon and approximately 70 Dolly Varden were captured in minnow traps in about 1 h. Length measurements were not taken on fish captured in the minnow traps.

Carrying Capacity Estimates

Application of the habitat model to Pass Creek suggests that availability of overwintering habitat limits coho salmon smolt production (Table 8). Minimum adult escapement necessary to fully seed available habitat with juveniles was estimated at 999, and marine survival greater than 5% would be necessary to produce the minimum number of adults (Table 9). The habitat type making the greatest contribution to smolt production was scour pool (75%; Table 10). Although riffle habitat was the predominant type in Pass Creek (48%), smolts produced by riffle habitat contribute little (3%) to overall smolt production in the system.

The production estimate for Pass Creek from the habitat model was similar to that of the Bradford et al. (1997) model based on stream length, but only if stream length measured during the habitat inventory was used (Table 11). The stream length for Pass Creek measured from DLG was considerably less than that measured during the habitat inventory, mainly due to lack of map detail for braided mainstem habitat and the absence of most tributary streams at the scale (1:63,360) of the DLG (Table 12). Production estimates for other Wide Bay streams using stream length measured from DLG and the Bradford et al. (1997) model ranged from 427 for Short Creek to 1,965 for Big Creek (Table 11).

Table 5. Summary of streams where the habitat inventory was completed in the Pass Creek watershed, 2006.

		Location (latitude and longitude, decimal degrees)			
		Mouth		End	
Stream Name[a]	Length (km)	North	West	North	West
Pass Creek	21.1	57.40088	156.35707	57.43065	156.48062
Bud Creek	0.2	57.42316	156.46625	57.42224	156.46684
Charlotte Creek	0.2	57.40566	156.36501	57.40685	156.36722
Cub Creek	1.1	57.40324	156.37698	57.39854	156.38373
Hog Creek[b]	0.6	57.41413	156.43382	57.41364	156.44017
Julia Creek	1.6	57.41703	156.43874	[c]	[c]
Last Creek[b]	0.4	57.41413	156.43382	57.41528	156.43666
Laurens Creek	0.2	57.42909	156.47722	57.42819	156.47809
Map Creek	0.8	57.41337	156.43201	57.40892	156.43346
Total	26.2				

[a] Except for Pass Creek, all tributary streams were un-named. Streams were named by the crew.
[b] Hog Creek and Last Creek entered Pass Creek within 2 m of each other.
[c] No coordinates were recorded.

Table 6. Summary of habitat composition surveyed in Pass Creek, 2006.

Habitat Type	Surface Area (m^2)	Percent Composition	Spawning Area (m^2)
Cascade	6,220	4	604
Rapid	9,070	6	123
Riffle	68,418	48	7,387
Glide	7,668	5	1,522
Trench Pool	--	0	--
Plunge Pool	303	< 1	18
Scour Pool	46,088	32	10,120
Dam Pool	--	0	--
Alcove	245	< 1	0
Beaver Pond	--	0	--
Backwater	5,214	4	<1
Total:	143,226		19,774

Table 7. Summary of snorkel surveys completed in Wide Bay streams, 2006. Mean density (standard error in parentheses) is reported as fish/m^2.

Stream	Sample Size	Juvenile Coho Salmon		Juvenile Dolly Varden	
		Number Observed	Mean Density	Number Observed	Mean Density
Des Moines Creek	2	5	0.02 (0.02)	7	0.03 (0.03)
Pass Creek	3	27	0.08 (0.04)	104	0.52 (0.31)

Table 8. Potential seasonal smolt production for juvenile coho salmon in Pass Creek calculated using the habitat limiting factor model of Nickelson (1998).

Season	Number of Smolts
Spawning	16,477,500
Spring	192,519
Summer	103,905
Winter	21,386

Table 9. Summary of stream characteristics and results of habitat limiting factor model of Nickelson (1998) for Pass Creek, 2006.

Model parameter	Estimate
Surface area (m^2)	143,226
Stream length (km)	26.2
Maximum smolt capacity (M)	19,200
Potential smolt density (C, fish/m^2)	0.13
Smolt capacity (fish/km)	733
Overwinter survival (S_{ow})	0.21
Egg-to-smolt survival (S_{smolt})	0.015
Required egg deposition (D_M)	1,248,992
Minimum number of adults necessary (A_M)	999
Potential production (PP_x)	
10% marine survival (PP_{10})	1,920
5% marine survival (PP_5)	960
3% marine survival (PP_3)	576

Table 10. Summary of coho salmon maximum smolt capacity estimates by habitat type during winter for Pass Creek using the habitat limiting factor model of Nickelson (1998).

		Smolt Capacity	
Habitat Type	Percent Composition	Number	Percent
Cascade	4	0	0
Rapid	6	91	<1
Riffle	48	684	3
Glide	5	920	4
Trench Pool	0	0	0
Plunge Pool	< 1	85	<1
Scour Pool	32	16,131	75
Dam Pool	0	0	0
Alcove	< 1	451	2
Beaver Pond	0	0	0
Backwater	4	3,024	14
Total:		21,386	

Table 11. Estimates of potential adult coho salmon production based on 5% marine survival using the Bradford et al. (1997) model based on stream length for streams in Wide Bay.

Stream	Length Source	Length (km)	Number of Adults
Pass Creek	Habitat inventory	26.2	1,177
Pass Creek	Digital line graph	15.0	686
Short Creek	Digital line graph	9.2	427
Des Moines Creek	Digital line graph	36.2	1,611
Big Creek	Digital line graph	44.4	1,965

Table 12. Comparison of Pass Creek lengths measured during habitat inventory and from USGS 1:63,360 digital line graphs.

	Stream Length (m)	
Habitat	Habitat Inventory	Digital Line Graphs
Mainstem	15,384	11,666
Side Channel	5,708	803
Tributary	5,068	2,530
Total	26,160	14,999

Discussion

Our initial sampling plan for Wide Bay streams (Table 2) was optimistic. The original plan was to complete work on Pass Creek, Des Moines Creek, and Short Creek, then move our base camp to Big Creek to finish the scheduled work. Even if we did not encounter difficulties in the work schedule due to weather, it is unlikely that all work would have been accomplished in the amount of time we had available (from early July to early August). Barring weather difficulties, we probably would have finished snorkel surveys in all streams except Short Creek; Short Creek was not accessible from our base camp between Pass and Des Moines creeks because of a shear cliff wall that made access along the beach impractical. It is unlikely that the habitat inventory would have been completed on Big Creek. Also, mark-recapture experiments would probably not have been successful in any streams as initially planned (i.e., setting block nets overnight).

In hindsight, we should have completed the juvenile sampling first and scheduled more time to complete the planned work in August. Completing juvenile surveys prior to July would not be practical because coho salmon fry would have been small (about 40 mm) and more difficult to count and identify with snorkel surveys because distinguishing characteristics are less apparent on smaller fish (Pollard et al. 1997). Smaller fish could also be less vulnerable to capture with minnow traps (Bloom 1976) and electrofishing (Riley and Fausch 1992; Reynolds 1996). The presence of spawning pink salmon later in the summer would not have affected our ability to classify and measure stream habitat, but it did prevent us from completing snorkel surveys because of turbid water and high densities of adults in pools. Spawning pink and chum salmon prevented us from completing snorkel surveys on portions of a similar stream on the Alaska Peninsula after mid-August in 2002, although we were able to complete snorkel surveys on the same stream the following year in late July and early August (Anderson and Hetrick 2004).

Another logistical difficulty that hindered our ability to complete work in 2006 was the amount of hiking necessary to access the study streams. The hike from our base camp to the mouth of either Pass Creek or Des Moines Creek was about 2 km, and the one-way hike to access the upper portions of Pass Creek took over 2.5 h. Relocating our base camp was not practical because there were no suitable sites closer to either stream. The one-way hike to the upper reaches of Big Creek from our planned base camp would have been about 8 km. As hiking was our only means of accessing the study streams, packing sampling gear and crew fatigue sometimes limited the amount of work that could be completed. The high density of brown bears made it impractical to cache sampling gear on the survey streams for any length of time, so most gear had to be packed back and forth each day from base camp. The use of a helicopter to access study streams would have allowed us to accomplish more work in any given day, but would have added considerably to the cost of the project.

Snorkel sampling was chosen to estimate juvenile coho salmon densities in pools based on previous work (Anderson and Hetrick 2004) and logistics. Although snorkel estimates may be less accurate and precise than mark-recapture or removal techniques (Hillman et al. 1992; Rodgers et al. 1992; Thurow and Schill 1996; Mullner et al. 1998), snorkel surveys allow for the sampling of more stream area in a given time compared to other methods (Hankin and Reeves 1988; Rodgers et al. 1992; Roni and Fayram 2000). Also, the potential high variability associated with the accuracy of individual snorkel counts may be offset by the ability to sample a larger proportion of the total stream (Hankin and Reeves 1988). Anderson and Hetrick (2004) found snorkel density estimates in Clear Creek to represent minimum values, although variability was low in pool habitat.

We chose mark-recapture techniques to calibrate our snorkel estimates in 2006. However, mark-recapture population estimates were not practical in Pass Creek because we were unable to keep block nets set. Although stream width (6 m) was not excessive in the pool where we attempted the estimate, high water velocities combined with floating debris breached the nets. The nets remained anchored and secure to the stream bottom, but the tops of both nets (upstream and downstream) became submerged within the first hour. The sample site was selected in one of the braided channels in anticipation of this problem, and only about half of the Pass Creek water volume was present. Block nets may have been maintained if structural methods (i.e., fence posts) were used to support the tops of the nets instead of tying them off to nearby vegetation. However, this probably would not have worked for the planned 24-h period without someone on site cleaning the nets constantly and this was not a viable alternative for safety reasons. We did not want to risk unnecessary encounters with brown bears, especially in the middle of the night.

We have successfully used block nets in other streams on the Alaska Peninsula to conduct removal estimates (Anderson and Hetrick 2004), and nets maintained closure for over 4 h with little effort. However, this was in a low gradient meandering channel (Clear Creek), whereas Pass Creek is a higher gradient, higher velocity stream. There was also less debris flow in Clear Creek than in Pass Creek. Numerous researchers have successfully used block nets to sample stream fish communities, and block nets are necessary to maintain closure within the sample reach (Peterson et al. 2005). We either need to sample low gradient reaches where we can keep a block net set overnight, choose sample sites with natural barriers (cascades and waterfalls) that prevent juvenile fish movement, or use a different technique that does not require block nets to be set for long periods.

Our goal for the mark-recapture estimates was to determine the bias associated with our snorkel estimates of juvenile coho salmon density in pools. Removal estimates using electrofishing have commonly been used to assess accuracy of snorkel counts (Hankin and Reeves 1988; Thurow and Schill 1996; Mullner et al. 1998; Roni and Fayram 2000). However, we chose mark-recapture because several researchers have found that removal estimates using electrofishing may also be biased (Riley and Fausch 1992; Rodgers et al. 1992; Riley et al. 1993; Thompson 2003; Peterson et al. 2004). Although removal estimates using electrofishing may be biased, the technique may be better suited than mark-recapture for sampling streams on the Alaska Peninsula. A removal estimate can be completed in a few hours, whereas a mark-recapture experiment can last over 24 h (Peterson et al. 2004; Rosenberger and Dunham 2005). The longer duration sets for the mark-recapture experiment are to allow marked fish to recover from the marking event and mix completely with unmarked fish in the sample unit. The shorter sampling duration required for a given pool with electrofishing removal techniques compared to mark-recapture would result in a higher probability that block nets would maintain population closure. Even though results from electrofishing removal estimates may also be biased, they should still provide useful information to assess the bias of snorkel estimates. In general, the usefulness of any population survey depends on obtaining unbiased, or nearly unbiased, and precise parameter estimates in a cost-efficient, logistically feasible manner (Thompson et al. 1998). Electrofishing removal estimates may be the best alternative for calibrating snorkel counts in Alaska Peninsula streams.

Few juvenile coho salmon were observed in scour pools in Pass and Des Moines creeks in 2006. Mean densities were well below those observed in other streams on the Alaska Peninsula and in other Pacific Northwest streams (Table 13), and well below the threshold believed to represent fully seeded habitat (1.0 fish/m^2; Nickelson et al. 1992) in coastal Oregon streams. Several explanations could account for these observed low densities. First, our limited sampling may have failed to detect coho salmon rearing in Pass and Des Moines creeks. We sampled very few pools (n = 5), and all were within the lower 3 km of both streams. However, we sampled numerous main-channel scour pools, side-channel scour pools, and backwater and off-channel habitats during training on lower Des Moines Creek, and observed few coho salmon in even the most optimal rearing habitats (backwaters and off-channel habitats). Also, although more coho salmon may have been present in mainstem or tributary habitat where we did not sample, no large schools of juvenile fishes were observed while completing the habitat inventory on mainstem Pass Creek and its tributaries, nor in the numerous backwater and off-channel habitats on mainstem Pass Creek that were transited on a daily basis while accessing our survey reaches. We did observe juvenile fish darting in pools, backwaters, and tributary streams while completing the habitat inventory on Pass Creek, but not in large numbers. Therefore, the low observed densities in Pass and Des Moines creeks are probably representative of the actual numbers of juvenile coho salmon present in both streams regardless of sampling effort and extent.

Another explanation for the low observed juvenile densities is that coho salmon populations in Pass and Des Moines creeks are depressed due to low marine survival, and low numbers of returning adults are responsible for the low numbers of juveniles observed. Although commercial harvest of coho salmon in the Kodiak District was above the 1994-2003 average (348,557; Dinnocenzo 2006) during 2004 (489,900; Dinnocenzo 2006) and 2005 (396,013; ADFG 2005), little harvest occurred in the Mainland District. In 2004, 18,193 coho salmon were harvested in the Mainland District, with only 4 harvested in the Cape Igvak section (directly outside of Wide Bay); no coho salmon were harvested in Wide Bay in 2004 (Dinnocenzo 2006). If low smolt-to-adult survival did occur, it was probably not due to the commercial fishery.

A third explanation for the low observed densities of juvenile coho salmon in Pass and Des Moines creeks is that catastrophic events (i.e., floods) affected juvenile production. There was evidence in both streams of severe flooding, with flood debris visible over 1 m above bankfull stage. However, we do not know if the observed evidence of flooding in Pass and Des Moines creeks was a result of fall and winter events or events caused by spring snowmelt. Flood events

Table 13. Mean summer densities (fish/m^2) of juvenile coho salmon in pool habitat observed throughout the Pacific Northwest and Alaska. Numbers in italics were interpolated from graphs in the source document; mean densities were not reported in numeric form. NR = not reported.

Stream	Location	Mean Density	Source
Pass Creek	SW Alaska	0.08 (0.04[a])	Current study
Des Moines Creek	SW Alaska	0.02 (0.02[a])	Current study
Clear Creek (2002)	SW Alaska	1.43 (0.34[a])	Anderson and Hetrick (2004)
Clear Creek (2003)	SW Alaska	0.43 (0.06[a])	Anderson and Hetrick (2004)
6 streams	SE Alaska	*0.20* (NR)	Bryant et al. (1998)
15 streams (1981-82)	Oregon	0.35 (0.16[b])	Nickelson et al. (1986)
15 streams (1983-85)	Oregon	0.31 (0.17[b])	Nickelson et al. (1986)
> 30 streams	Oregon	*1.30* (NR)	Nickelson et al. (1992)

[a] Standard error.
[b] Standard deviation.

can occur any time between September and May for mountain streams on the Alaska Peninsula. Once snow has accumulated in the mountains, rain-on-snow events are possible with weather patterns that subject the area to warm Pacific Ocean storms throughout the fall and winter.

Flood effects on coho salmon populations would be different depending on when events occur. If flooding occurs during egg incubation, scouring and bed load movement can crush or wash out developing eggs and alevins (Seegrist and Gard 1972; Holtby and Healy 1986; Erman et al. 1988; Sandercock 1991; Montgomery et al. 1996; DeVries 1997). Floods can also displace juvenile fish at other times of the year (Sandercock 1991; Bell et al. 2001). Winter floods can cause high mortality of juvenile coho salmon (Tschaplinski and Hartman 1983; Brown and Hartman 1988), and the lack of suitable refuge habitat (beaver ponds, backwaters, alcoves, and other off-channel areas) from high water velocities during winter floods is thought to limit coho salmon production in many coastal systems (Mason 1976; Nickelson et al. 1992). Pass Creek lacks much refuge habitat from flood events (Table 6), and the habitat composition in Des Moines Creek appears to be similar. However, it is unknown to what extent juvenile coho salmon are able to utilize tributary streams in both systems as refuges from flood events.

A final explanation for the low observed densities of juvenile coho salmon in Pass and Des Moines creeks is that habitat quality is low for coho salmon. The habitat model identifies a lack of overwintering habitat as the limiting factor for smolt production in Pass Creek (Table 8) and other streams on the Alaska Peninsula (Anderson and Hetrick 2004), mainly due to the lack of suitable refuge habitat from winter floods (Table 6; beaver ponds, backwaters, alcoves). However, aspects of the geomorphology of Pass and Des Moines creeks are different from other streams we have inventoried on the Alaska Peninsula that may further limit production beyond predictions of the habitat model. Most streams in the Perryville and Clear Creek drainages that we surveyed in 2002 and 2003 were primarily low gradient meandering channels on wide, well developed flood plains (Anderson and Hetrick 2004). These streams correspond to the C-type channels described by Rosgen (1994) and the pool-riffle reach morphology of Montgomery and Buffington (1997). However, Pass and Des Moines creeks (Figures 2 and 3) were primarily higher gradient riffle-dominated systems confined in relatively narrow mountain valleys corresponding to the B-type channels of Rosgen (1994) and the plane-bed and forced pool-riffle reach morphologies of Montgomery and Buffington (1997). It is therefore not surprising that more riffle, rapid, and cascade habitat was present in Pass Creek than in the other streams surveyed (Table 14). Nearly 60% of available habitat in Pass Creek was comprised of these three habitat types, whereas in the four other streams where we have completed habitat surveys, riffles, rapids, and cascades make up only about 30% of available habitat.

Pass and Des Moines creeks also had several reaches of lower gradient, braided channels throughout their lengths (D-type channels; Rosgen 1994). These reaches occurred when the flood plain became less confined and gradient decreased, allowing the streams to dissipate energy and deposit sediment. Much of the available spawning habitat for coho salmon probably occurs in these lower gradient reaches in Pass Creek. Montgomery et al. (1999) predict that large, fall-spawning salmonids should not be able to spawn successfully in higher gradient reaches (> 3%) in systems that are primarily influenced by winter rain-induced floods because bankfull flood events are sufficient to mobilize bed load below typical egg burial depths in those reaches. This hypothesis is based on channel morphologies, bed scour, and egg burial depths, and has been shown to predict coho salmon spawning distributions in coastal Oregon streams. The bed scour hypothesis also predicts that large fall-spawning salmonids should be able to spawn successfully in lower gradient reaches (< 3%) in systems influenced by winter flooding, because bankfull flood events typically do not mobilize bed load below egg burial depths in those reaches (Montgomery et al. 1999). However, the lower gradient braided reaches in Pass Creek are relatively unstable and can be more susceptible to channel scour, deposition, lateral movement, and bedload movement (Gordon et al. 1992; Rosgen 1994). If winter flood events exceed bankfull stage and mobilize bedload below egg burial depths in the braided reaches of Pass and Des Moines creeks, low egg-to-fry survival following a flood event the previous fall or winter could account for the low juvenile densities observed in 2006.

Pass Creek had the lowest maximum smolt capacity, potential smolt density, overwinter survival, egg-to-smolt survival, and potential production estimates of any of the other systems where the habitat model has been applied on the Alaska Peninsula (Table 15). These results are driven by the habitat composition observed in Pass Creek, which is in turn influenced by basin-scale geomorphology (Lanka et al. 1987; Richards et al. 1996; Montgomery and Buffington 1997). Overall channel morphology may be just as important as site-specific habitat composition in determining the potential for coho salmon production in many Alaska Peninsula streams. Big Creek, at the northern end of Wide Bay, is probably the largest producer of coho salmon in the area, not just in terms of available habitat (stream length; Table 11), but also in terms of channel morphology. Big Creek is a meandering channel on a wide, well developed flood plain (C-type channel; pool-riffle morphology; Figure 4), whereas Pass and Des Moines creeks (Figures 2 and 3) are not. The first step in any broad scale population monitoring/assessment on the Alaska Peninsula should initially concentrate efforts on streams with the greatest potential to support coho salmon production based on past surveys, local knowledge, and channel morphology, gradient, valley width, glacial influence, and other attributes that can be inferred from maps or remote sensing. This type of information suggested that Big Creek was the best coho salmon habitat of all the Wide Bay streams; however, we were not able to sample Big Creek in 2006.

Table 14. Comparison of habitat composition surveyed (percent) in Pass Creek, 2006, and in streams near Perryville and Clear Creek, 2002 and 2003 (from Anderson and Hetrick 2004).

Habitat Type	Pass Creek	Kametolook River	Three Star River	Long Beach River	Clear Creek
Cascade	4	< 1	0	< 1	< 1
Rapid	6	1	0	< 1	< 1
Riffle	48	32	29	28	21
Glide	5	26	22	16	9
Trench Pool	0	< 1	0	< 1	0
Plunge Pool	< 1	< 1	< 1	< 1	< 1
Scour Pool	32	31	40	40	18
Dam Pool	0	< 1	0	< 1	0
Alcove	< 1	< 1	< 1	< 1	< 1
Beaver Pond[a]	0	6	2	0	49
Backwater	4	1	7	14	2
Surface Area (m^2)	143,226	160,772	103,546	157,910	141,736

[a] Beaver pond habitat in the Kametolook and Three Star systems consisted of small natural lakes and swamps.

Table 15. Summary of results of the habitat limiting factor model of Nickelson (1998) for Pass Creek, 2006, and streams near Perryville and Clear Creek, 2002 and 2003 (from Anderson and Hetrick 2004).

Model parameter	Pass Creek	Kametolook	Three Star	Long Beach	Clear Creek
Surface area (m^2)	143,226	160,772	103,546	157,910	141,736
Stream length (km)	26.2	43.7	27.3	42.5	12.9
Maximum smolt capacity (M)	19,200	26,000	20,400	35,600	74,200
Potential smolt density (C, fish/m^2)	0.13	0.16	0.20	0.23	0.52
Smolt capacity (fish/km)	733	595	747	838	5,752
Overwinter survival (S_{ow})	0.21	0.24	0.27	0.28	0.40
Egg-to-smolt survival (S_{smolt})	0.015	0.017	0.019	0.020	0.029
Minimum number of adults necessary (A_M)	999	1,209	852	1,392	2,067
Potential production (PP_x)					
10% marine survival (PP_{10})	1,920	2,600	2,040	3,560	7,420
5% marine survival (PP_5)	960	1,300	1,020	1,790	3,710
3% marine survival (PP_3)	576	780	612	1,068	2,226

Broad scale application of the Nickelson (1998) or Bradford et al. (1997) models to other streams on the Alaska Peninsula is not appropriate at this time without some prior knowledge of stream geomorphology. Although both models appear to provide reasonable estimates of coho salmon production for low gradient systems (Anderson and Hetrick 2004), they overestimate coho salmon production for higher gradient streams such as Pass Creek. The underlying assumption of the Nickelson (1998) model is that when a specific habitat is in short supply, a bottleneck exists that may subject a cohort to density-dependent mortality, which may lead to an under seeding of habitats used by subsequent life stages. This general assumption may be more applicable to low gradient systems than to higher gradient streams like Pass Creek. Lower gradient streams are probably not limited by low egg-to-fry survival caused by bedload movement (Montgomery et al. 1999), and density-dependent mortality at later life stages may be important in affecting overall productivity. Higher gradient streams like Pass Creek are probably more limited by low egg-to-fry survival caused by bedload scour (Montgomery et al. 1999), and density-dependent mortality at later life stages probably does not affect overall coho salmon production, regardless of available habitat. The Nickelson (1998) or Bradford et al. (1997) models should only be applied to low gradient streams or stream reaches that are not limited by egg-to-fry survival as predicted by the bed scour hypothesis of Montgomery et al. (1999).

One of our goals for the 2006 work in Wide Bay was to apply other techniques such as remote sensing and geographic information system (GIS) technology to model coho salmon production in individual streams over a broad geographic area. However, even something as simple as determining stream lengths using DLG for use in modeling was problematic, and discrepancies in measurements can influence model results (Table 11). At the scale of the source maps available for the Alaska Peninsula (1:63,360), numerous small tributary streams are not mapped. In Pass Creek, for example, only one tributary stream was present on the DLG (Table 16, Figure 2), whereas we completed the habitat inventory on eight tributary streams that provided rearing habitat for juvenile coho salmon (Table 5). The DLG also underrepresented the amount of mainstem and side channel habitat in Pass Creek (Table 16). Results of similar comparisons for other streams where we have completed habitat inventories were varied. In Clear Creek, the stream length measured from DLG overestimates the amount of rearing habitat available for coho salmon, but DLG stream lengths are comparable to lengths measured during the habitat inventory for Three Star River (Table 16). The difference in Clear Creek is mainly due to about 12 km of tributary streams on the DLG that are above barriers to coho salmon migration and were therefore not measured during the habitat inventory, and to a 3-km tributary stream on the DLG that no longer exists on the ground. As in Pass Creek, many smaller tributary streams in Clear Creek and Three Star River were not present on the DLG (Table 16). Larger scale maps (i.e., 1:24,000) provide better representation of actual stream networks, but they are not available for most of Alaska.

The ability to measure accurate stream gradient from maps would allow us to determine in advance if streams or stream reaches could support coho salmon spawning based on the bed scour hypothesis of Montgomery et al. (1999). However, calculating overall stream gradient in Pass Creek using changes in elevation estimated from topographic maps (75 m) and digital elevation models (DEM; 110 m) and a stream length of 11.7 km for mainstem habitat measured from DLG (Table 12) both yield gradient estimates of less than 1%, which does not correspond to field observations. Although we did not measure overall stream or reach gradient in the field, overall channel morphology in Pass Creek corresponds to Rosgen (1994) B-type channels, which typically have gradients between 2 and 4%, and to the plane-bed morphology of Montgomery and Buffington (1997), with typical gradients between 1.5 and 3%. It should be noted that the values reported by Rosgen (1994) and Montgomery and Buffington (1997) are generalizations of many field observations, and gradient measurements for a given channel type or morphology outside of the ranges reported are possible. Regardless, Pass Creek is a relatively high gradient system based on field observations, whereas overall stream gradient estimated from topographic maps was low (< 1%).

Table 16. Comparison of stream lengths measured during a habitat inventory (Survey) compared to measurements from USGS 1:63,360 digital line graphs (DLG). Number of tributary streams identified in parentheses. Data for Clear Creek and Three Star River surveys are from Anderson and Hetrick (2004).

	Stream Length (km)					
	Total		Mainstem		Tributary (*n*)	
Stream	Survey	DLG	Survey	DLG	Survey	DLG
Pass Creek	26.2	15.0	21.1	12.5	5.1 (*n* = 8)	2.5 (*n* = 1)
Clear Creek	12.9	25.4	6.9	6.0	6.0 (*n* = 13)	19.4 (*n* = 3)
Three Star River	27.3	25.6	9.9	11.7	17.5 (*n* = 10)	13.9 (*n* = 3)

Although investigators commonly use map-derived measurements (i.e., stream length, gradient) in fisheries analyses and modeling, few have assessed their accuracy compared to field measurements. Morisawa (1957) compared stream reach lengths measured in the field with lengths derived from 1:24,000 scale topographic maps, and found that map-derived measurements were always less than those measured in the field. Firman and Jacobs (2002) found similar results using 1:24,000 scale topographic maps in a commercially-available software package; stream reach lengths measured from maps were about 6% less than lengths measured in the field, although map-derived measurements were more precise. Isaak et al. (1999) found that stream gradient measurements using digitized 1:24,000 scale maps in a GIS were precise, but over-estimated reach gradients compared to field measurements, which the authors attributed to the inability of maps to mimic stream sinuosity. Montgomery et al. (1999) also found that reach gradients measured from 1:24,000 topographic maps could be in error by as much as ±100% compared to field measurements.

Maps are abstractions of the real world, and the amount of detail that can be portrayed is limited. Smaller scale maps available for use in southwest Alaska (1:63,360) are not accurate representations of stream networks, most apparent in their lack of detail for tributary streams. Any digital layers developed from them for use in a GIS will also be flawed representations of reality. However, few readily-available and inexpensive alternatives are available for creating better stream maps. Stream networks can be generated from DEM (Tribe 1992), although as with maps, large-scale DEM are not available for most of Alaska. However, based on observations of existing DEM and DLG for Wide Bay, stream networks generated from DEM would probably include more tributary streams (Figure 5). Other remote sensing technologies such as satellite and aerial imagery provide alternatives to map, measure, and classify habitat characteristics over broad geographic areas. Multi-spectral digital imagery has been used to classify depth, velocity, and habitat types (i.e., pools and riffles) in several large river systems at a spatial resolution of less than 1 m (Whited et al. 2002a, 2002b; Lorang et al. 2005), and similar technology (hyperspectral imagery) has been used on smaller streams with similar resolution (Marcus 2002; Marcus et al. 2003). The amount of vegetative canopy, however, would limit applications of this type of technology because many tributary streams we surveyed were totally enclosed by overhead vegetation, and would not be visible from aerial images.

Recommendations

Although we believe the techniques investigated with this project such as application of habitat-based smolt production models and the use of juvenile abundance as a surrogate for adult escapement to monitor coho salmon populations have high potential for success, we do not recommend moving forward with broad scale application of these techniques on the Pacific Ocean side of the Alaska Peninsula at this time. The habitat models only appear to produce valid estimates of potential coho salmon production for low gradient systems, and we have yet to verify several key parameters used in the model (smolt production estimates, egg-to-life stage survival estimates, overwinter survival estimates, smolt-to-adult survival estimates) for streams in southwest Alaska. Although we do believe the Nickelson (1998) and Bradford et al. (1997) models provide reasonable estimates of potential coho salmon production in low gradient streams, a detailed project should be completed to determine coho salmon smolt production, overwinter survival, and smolt-to-adult survival for one or more streams on the Pacific Ocean side of the Alaska Peninsula. This would allow us to further validate and refine the Nickelson (1998) habitat model for use in southwest Alaska.

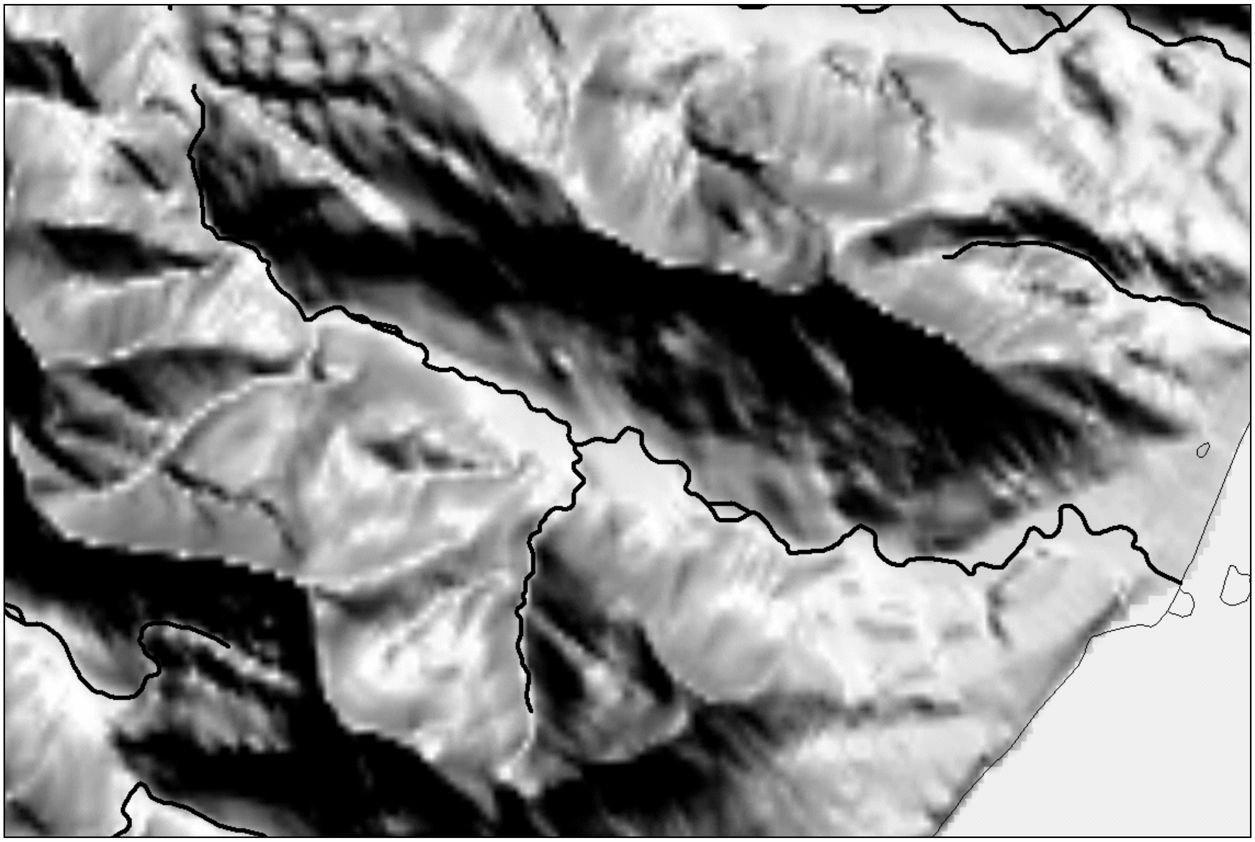

Figure 5. Digital line graph (DLG; 1:63,360) of Pass Creek overlaid on digital elevation model (DEM; 15-minute). Converging contours of DEM show where tributary streams exist that are not represented on DLG.

Sampling juvenile coho salmon abundance as a surrogate for adult escapement in numerous streams in a given field season is not practical, mainly due to the logistics of getting to the streams. Accessing numerous streams in a relatively short time window with a sampling crew is possible, but would require the use of a helicopter and would be expensive. An alternative to monitoring multiple streams would be to choose a few index streams that are easy to access with aircraft (i.e., near a runway) such as streams near Yantarni airstrip, Ivanof Village, or streams on Kodiak Island. Juvenile abundance in these index streams could be monitored annually to identify any population declines that would warrant further investigation. Also, we need to validate the threshold density of 1.0 fish/m^2 in pool habitat as representative of fully seeded habitat (Nickelson et al. 1992) for streams on the Alaska Peninsula. In order to make management decisions based on juvenile abundance, we need to know what summer densities constitute "good" production. This could be accomplished as a separate project, or concurrent with the life history project mentioned above.

Monitoring adult coho salmon escapement on the Pacific Ocean side of the Alaska Peninsula is difficult because of remoteness and bad weather. Although aerial surveys are affected by weather and local water quality conditions and are not estimates of total abundance (Anderson 2006), they may provide the best alternative for managers to monitor coho salmon populations on the Alaska Peninsula until projects to validate habitat model parameters and juvenile abundance thresholds can be funded. We have used aerial surveys to monitor coho salmon populations in streams near Perryville since 2003, and trends in run timing and abundance are becoming apparent for some streams (Anderson 2006). Several representative streams could be selected for annual monitoring based on previous surveys, local knowledge, and the potential for coho salmon production. Surveys could be scheduled concurrently with the ongoing surveys near Perryville to minimize costs.

Acknowledgements

We thank Lora Tennant, Zack Brock, Drew Lane, and Chris Logan for their work in Wide Bay, 2006. We also wish to thank Cecil Shuman of C-Air for providing aircraft services, and staff at the Alaska Department of Fish and Game in Kodiak for providing information and assistance.

References

ADFG (Alaska Department of Fish and Game). 2002. Customary and traditional use worksheet salmon: Chignik Management Area. Report to the Alaska Board of Fisheries. Alaska Department of Fish and Game, Division of Subsistence, Anchorage, Alaska.

ADFG (Alaska Department of Fish and Game). 2005. Kodiak management area 2005 commercial salmon fishery summary. Alaska Department of Fish and Game, Kodiak, Alaska.

Anderson, J. L. 2004. Estimation of coho salmon escapement in streams adjacent to Perryville, Alaska Peninsula National Wildlife Refuge, 2003. U. S. Fish and Wildlife Service, King Salmon Fish and Wildlife Field Office, Alaska Fisheries Data Series Report Number 2004-2, King Salmon, Alaska.

Anderson, J. L. 2005. Abundance and run timing of adult Pacific salmon in Big Creek, Becharof National Wildlife Refuge, 2004. U. S. Fish and Wildlife Service, King Salmon Fish and Wildlife Field Office, Alaska Fisheries Data Series Report Number 2005-12, King Salmon, Alaska.

Anderson, J. L. 2006. Estimation of coho salmon escapement in streams adjacent to Perryville and sockeye salmon escapement in Chignik Lake tributaries, Alaska Peninsula National Wildlife Refuge, 2006. U. S. Fish and Wildlife Service, King Salmon Fish and Wildlife Field Office, Alaska Fisheries Data Series Report Number 2006-15, King Salmon, Alaska.

Anderson, J. L., and N. J. Hetrick. 2004. Carrying capacity of habitats used seasonally by coho salmon in the Kametolook River, Alaska Peninsula National Wildlife Refuge, 2002-2003. U. S. Fish and Wildlife Service, King Salmon Fish and Wildlife Field Office, Alaska Fisheries Technical Report Number 73, King Salmon, Alaska.

Anderson, J. L., K. S. Whitton, K. K. Cornum, and T. D. Auth. 2004. Abundance and run timing of adult Pacific salmon in Big Creek, Becharof National Wildlife Refuge, 2003. U. S. Fish and Wildlife Service, King Salmon Fish and Wildlife Field Office, Alaska Fisheries Data Series Report Number 2004-7, King Salmon, Alaska.

Bell, E., W. G. Duffy, and T. D. Roelofs. 2001. Fidelity and survival of juvenile coho salmon in response to a flood. Transactions of the American Fisheries Society 130:450-458.

Bisson, P. A., J. L. Nielsen, R. A. Palmason, and L. E. Groves. 1982. A system of naming habitat types in small streams with examples of habitat utilization by salmonids during low streamflow. Pages 62-73 *in* N. B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. Proceedings of a symposium held 28-30 October, 1981, Western Division of the American Fisheries Society, Portland, Oregon.

Bloom, A. M. 1976. Evaluation of minnow traps for estimating populations of juvenile coho salmon and Dolly Varden. Progressive Fish-Culturist 38:99-101.

Bradford, M. J., G. C Taylor, and J. A. Allan. 1997. Empirical review of coho salmon smolt abundance and the prediction of smolt production at the regional level. Transactions of the American Fisheries Society 126:49-64.

Brennan, K., J. Wadle, and D. Gretsch. 2005. Kodiak management area harvest strategy for the 2005 commercial salmon fishery. Alaska Department of Fish and Game, Fishery Management Report No. 05-32, Anchorage, Alaska.

Brown, T. G., and G. F. Hartman. 1988. Contribution of seasonally flooded lands and minor tributaries to the production of coho salmon in Carnation Creek, British Columbia. Transactions of the American Fisheries Society 117:546-551.

Bryant, M. D., D. N. Swanston, R. C. Wissmar, and B. E. Wright. 1998. Coho salmon populations in the karst landscape of North Prince of Wales Island, southeast Alaska. Transactions of the American Fisheries Society 127:425-433.

Burgner, R. L. 1991. Life history of sockeye salmon (*Oncorhynchus nerka*). Pages 1-118 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. University of British Columbia Press, Vancouver, British Columbia.

Cederholm, C. J., M. D. Kunze, T. Murota, and A. Sibatani. 1999. Pacific salmon carcasses: essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. Fisheries 24 (10):6-15.

Darimont, C. T., T. E. Reimchen, and P. C. Paquet. 2003. Foraging behaviour by gray wolves on salmon streams in coastal British Columbia. Canadian Journal of Zoology 81:349-353.

DeVries, P. 1997. Riverine salmonid egg burial depths: review of published data and implications for scour studies. Canadian Journal of Fisheries and Aquatic Sciences 54:1685-1698.

Dinnocenzo, J. 2006. Kodiak management area commercial salmon annual management report, 2004. Alaska Department of Fish and Game, Fishery Management Report No. 06-14, Anchorage, Alaska.

Dolloff, A., J. Kershner, and R. Thurow. 1996. Underwater observations. Pages 533-554 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Dombeck, M., J. Hammill, and W. Bullen. 1984. Fisheries management and fish dependent birds. Fisheries 9 (2): 2-4.

Erman, D. C., E. D. Andrews, and M. Yoder-Williams. 1988. Effects of winter floods on fishes in the Sierra Nevada. Canadian Journal of Fisheries and Aquatic Sciences 45:2195-2200.

Firman, J. C., and S. E. Jacobs. 2002. Comparison of stream reach lengths measured in the field and from maps. North American Journal of Fisheries Management 22:1325-1328.

Gordon, N. D., T. A. McMahon, and B. L. Finlayson. 1992. Stream hydrology: an introduction for ecologists. John Wiley & Sons Ltd., Chichester, England.

Hankin, D. G., and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45:834-844.

Heard, W. R. 1991. Life history of pink salmon (*Oncorhynchus gorbuscha*). Pages 119-230 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. University of British Columbia Press, Vancouver, British Columbia.

Hetrick, N. J., and M. J. Nemeth. 2003. Survey of coho salmon runs on the Pacific Coast of the Alaska Peninsula and Becharof National Wildlife Refuges, 1994 with estimates of escapement for two small streams in 1995 and 1996. U. S. Fish and Wildlife Service, King Salmon Fish and Wildlife Field Office, Alaska Fisheries Technical Report 63, King Salmon, Alaska.

Hillman, T. W., J. W. Mullan, and J. S. Griffith. 1992. Accuracy of underwater counts of juvenile chinook salmon, coho salmon, and steelhead. North American Journal of Fisheries Management 12:598-603.

Holtby, L. B., and M. C. Healey. 1986. Selection for adult size in female coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 43:1946-1959.

Irvine, J. R., R. C. Bocking, K. K. English, and M. Labelle. 1992. Estimating coho salmon (*Oncorhynchus kisutch*) spawning escapements by conducting visual surveys in areas selected using stratified random and stratified index sampling designs. Canadian Journal of Fisheries and Aquatic Sciences 49:1972-1981.

Isaak, D. J., W. A. Hubert, and K. L. Krueger. 1999. Accuracy and precision of stream reach water surface slopes estimate in the field and from maps. North American Journal of Fisheries Management 19:141-148.

Jauquet, J., N. Pittman, J. A. Heinis, S. Thompson, N. Tatyama, and J. Cederholm. 2003. Observations of chum salmon consumption by wildlife and changes in water chemistry at Kennedy Creek during 1997 – 2000. Pages 71-88 *in* J. G. Stockner, editor. Nutrients in salmonid ecosystems: sustaining production and biodiversity. American Fisheries Society, Symposium 34, Bethesda, Maryland.

Johnson, J. and E. Weiss. 2006. Catalog of waters important for spawning, rearing, or migration of anadromous fishers – Southwest Region, effective September 15, 2006. Alaska Department of Fish and Game, Special Publication No. 06-18, Anchorage, Alaska.

Lanka, R. P., W. A. Hubert, and T. A. Wesche. 1987. Relations of geomorphology to stream habitat and trout standing stock in small Rocky Mountain streams. Transactions of the American Fisheries Society 116:21-28.

Lorang, M. S., D. C. Whited, F. R. Hauer, J. S. Kimball, and J. A. Stanford. 2005. Using airborne multispectral imagery to evaluate geomorphic work across floodplains of gravel-bed rivers. Ecological Applications 15:1209-1222.

Marcus, W. A. 2002. Mapping of stream microhabitats with high spatial resolution hyperspectral imagery. Journal of Geographical Systems 4:113-126.

Marcus, W. A., C. J. Legleiter, R. J. Aspinall, J. W. Boardman, and R. L. Crabtree. 2003. High spatial resolution hyperspectral mapping of in-stream habitats, depths, and woody debris in mountain streams. Geomorphology 55:363-380.

Mason, J. C. 1976. Response of underyearling coho salmon to supplemental feeding in a natural stream. Journal of Wildlife Management 40:775-788.

Meehan, W. R., and T. C. Bjornn. 1991. Salmonid distributions and life histories. Pages 47-82 *in* W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Bethesda, Maryland.

Montgomery, D. R., and J. M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin 109:596-611.

Montgomery, D. R., J. M. Buffington, N. P. Peterson, D. Shuett-Hames, and T. P. Quinn. 1996. Stream-bed scour, egg burial depths, and the influence of spawning salmon on bed surface mobility and embryo survival. Canadian Journal of Fisheries and Aquatic Sciences 53:1061-1070.

Montgomery, D. R., E. M. Beamer, G. R. Pess, and T. P. Quinn. 1999. Channel type and salmonid spawning distribution and abundance. Canadian Journal of Fisheries and Aquatic Sciences 56:377-387.

Morisawa, M. 1957. Accuracy of determination of stream lengths from topographic maps. Transactions of the American Geophysical Union 38:86-88.

Mullner, S. A., W. A. Hubert, and T. A. Wesche. 1998. Snorkeling as an alternative to depletion electrofishing for estimating abundance and length-class frequencies of trout in small streams. North American Journal of Fisheries Management 18:947-953.

Nelson, P. A., and D. S. Lloyd. 2001. Escapement goals for Pacific salmon in the Kodiak, Chignik, and Alaska Peninsula/Aleutian Islands areas of Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 4K01-66, Kodiak, Alaska.

Nickelson, T. E. 1998. A habitat-based assessment of coho salmon production potential and spawner escapement needs for Oregon coastal streams. Oregon Department of Fish and Wildlife Information Reports Number 98-4, Portland, Oregon.

Nickelson, T. E., M. F. Solazzi, and S. L. Johnson. 1986. Use of hatchery coho salmon (*Oncorhynchus kisutch*) presmolts to rebuild wild populations in Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Sciences 43:2443-2449.

Nickelson, T. E., J. D. Rodgers, S. L. Johnson, and M. F. Solazzi. 1992. Seasonal changes in habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Sciences 49:783-789.

Olsen, J. B., S. J. Miller, W. J. Spearman, and J. K. Wenburg. 2003. Patterns of intra- and inter-population genetic diversity in Alaskan coho salmon: Implications for conservation. Conservation Genetics 4:557-569.

Overton, C. K., S. P. Wollrab, B. C. Roberts, and M. A. Radko. 1997. R1/R4 (Northern/Intermountain Regions) fish and fish habitat standard inventory procedures handbook. USDA Forest Service, General Technical Report INT-GTR-346, Ogden, Utah.

Pappas, G. E., P. Tschersich, and K. J. Clark. 2005. Chignik Management Area annual finfish management report, 2001. Alaska Department of Fish and Game, Commercial Fisheries Division, Fishery Management Report No. 05-30, Anchorage, Alaska.

Peterson, J. T., R. F. Thurow, and J. W. Guzevich. 2004. An evaluation of multipass electrofishing for estimating the abundance of stream-dwelling salmonids. Transactions of the American Fisheries Society 133:462-475.

Peterson, J. T., N. P. Banish, and R. F. Thurow. 2005. Are block nets necessary?: movement of stream-dwelling salmonids in response to three common survey methods. North American Journal of Fisheries Management 25:732-743.

Pollard, W. R., G. F. Hartman, C. Groot, and P. Edgell. 1997. Field identification of coastal juvenile salmonids. Harbour Publishing, Madeira Park, British Columbia.

Quinn, T. P., S. M. Gende, G. T. Ruggerone, and D. E. Rogers. 2003. Density-dependant predation by brown bears (*Ursus arctos*) on sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 60:553-562.

Reynolds, J. B. 1996. Electrofishing. Pages 221-253 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Richards, C., L. B. Johnson, and G. E. Host. 1996. Landscape-scale influences on stream habitats and biota. Canadian Journal of Fisheries and Aquatic Sciences 53 (Supplement 1):295-311.

Riley, S. C., and K. D. Fausch. 1992. Underestimation of trout population size by maximum-likelihood removal estimates in small streams. North American Journal of Fisheries Management 12:768-776.

Riley, S. C., R. L. Haedrich, and R. J. Gibson. 1993. Negative bias in removal estimates of Atlantic salmon parr relative to stream size. Journal of Freshwater Ecology 8:97-101.

Rodgers, J. D., M. F. Solazzi, S. L. Johnson, and M. A. Buckman. 1992. Comparison of three techniques to estimate juvenile coho salmon populations in small streams. North American Journal of Fisheries Management 12:79-86.

Roni, P., and A. Fayram. 2000. Estimating winter salmonid abundance in small western Washington streams: a comparison of three techniques. North American Journal of Fisheries Management 20:683-692.

Rosenberger, A. E., and J. B. Dunham. 2005. Validation of abundance estimates from mark-recapture and removal techniques for rainbow trout captured by electrofishing in small streams. North American Journal of Fisheries Management 25:1395-1410.

Rosgen, D. L. 1994. A classification of natural rivers. Catena 22:169-199.

Ruggerone, G. T., R. Hanson, and D. E. Rogers. 2000. Selective predation by brown bears (*Ursus arctos*) foraging on spawning sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Zoology 78:974-981.

Sandercock, F. K. 1991. Life history of coho salmon (*Oncorhynchus kisutch*). Pages 395-446 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. University of British Columbia Press, Vancouver, British Columbia.

Schwarz, L. 1997. Area management report for the recreational fisheries of the Kodiak and Alaska Peninsula/Aleutian Islands regulatory areas, 1996. Alaska Department of Fish and Game, Sport Fish Division. Fishery Management Report No. 97-2, Anchorage, Alaska.

Seegrist, D. W., and R. Gard. 1972. Effects of floods on trout in Sagehen Creek, California. Transactions of the American Fisheries Society 101:478-482.

Shaul, A. R., and J. J. Dinnocenzo. 2002. Annual summary of the commercial salmon fishery and a report on salmon subsistence and personal use fisheries for the Alaska Peninsula, Aleutian Islands, and Atka-Amlia Islands Management Areas, 2001. Regional Information Report No. 4K02-22, Alaska Department of Fish and Game, Division of Commercial Fisheries, Kodiak, Alaska.

Thompson, W. L. 2003. Hankin and Reeves' approach to estimating fish abundance in small streams: limitations and alternatives. Transactions of the American Fisheries Society 132:69-75.

Thompson, W. L., G. C. White, and C. Gowan. 1998. Monitoring vertebrate populations. Academic Press, San Diego, California.

Thurow, R. F., and D. J. Schill. 1996. Comparison of day snorkeling, night snorkeling, and electrofishing to estimate bull trout abundance and size structure in a second-order Idaho stream. North American Journal of Fisheries Management 16:314-323.

Tribe, A. 1992. Automated recognition of valley lines and drainage networks from digital elevation models: a review and a new method. Journal of Hydrology 139:263-293.

Tschaplinski, P. J., and G. F. Hartman. 1983. Winter distribution of juvenile coho salmon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Columbia, and some implications for overwinter survival. Canadian Journal of Fisheries and Aquatic Sciences 40:452-461.

USFWS (U. S. Fish and Wildlife Service). 1994. Alaska Peninsula Becharof National Wildlife Refuges fishery management plan fiscal years 1994-1998, King Salmon, Alaska.

Whited, D., J. A. Stanford, and J. S. Kimball. 2002a. Application of airborne multispectral digital imagery to quantify riverine habitats at different base flows. River Research and Applications 18:583-594.

Whited, D., J. A. Stanford, and J. S. Kimball. 2002b. Application of airborne multi-spectral digital imagery to characterize the riverine habitat. Verhandlungen der Internationale Vereinigung fur Theoretische und Angewandte Limnologie 28:1373-1380.

Whitton, K. S. 2003. Abundance and run timing of adult Pacific salmon in Big Creek, Becharof National Wildlife Refuge. U. S. Fish and Wildlife Service, King Salmon Fish and Wildlife Field Office, Alaska Fisheries Technical Report Number 65, King Salmon, Alaska.

Zar, J. H. 1996. Biostatistical analysis, third edition. Prentice Hall, Upper Saddle River, New Jersey.

Appendix A. Summary of daily work activities in Wide Bay, 2006

Date	Activity
10-Jul	Weather prohibitive for accessing Wide Bay
11-Jul	Weather prohibitive for accessing Wide Bay
12-Jul	Arrive in Wide Bay, set up camp
13-Jul	Habitat inventory - Pass Creek
14-Jul	Habitat inventory - Pass Creek
15-Jul	Snorkel training - Des Moines Creek
16-Jul	No work, crew change and camp re-supply
17-Jul	No work - high water
18-Jul	No work - high water
19-Jul	No work - high water
20-Jul	Habitat inventory - Pass Creek
21-Jul	Snorkel training (1/2) and surveys (1/2) - Des Moines Creek
22-Jul	Habitat inventory - Pass Creek
23-Jul	No work - high water
24-Jul	No work - high water
25-Jul	Habitat inventory - Pass Creek
26-Jul	Habitat inventory - Pass Creek
27-Jul	Mark-recapture attempt - Pass Creek
28-Jul	No work, crew change and camp re-supply
29-Jul	Attempted work, brown bear issues
30-Jul	Attempted work, brown bear issues
31-Jul	No work - high water
1-Aug	No work - high water
2-Aug	Crew change and camp re-supply, snorkel Pass Creek 1/2 day
3-Aug	No work - high water
4-Aug	No work - high water
5-Aug	No work - high water
6-Aug	Habitat inventory - Pass Creek
7-Aug	Habitat inventory - Pass Creek
8-Aug	Camp breakdown
9-Aug	Depart Wide Bay