

Elwha River baseline monitoring report 2009

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269 **Introduction**

270 The goal of our initial 2009 baseline monitoring effort in the Elwha river basin was three-fold:

271 1. Identify, develop, and test biological and physical monitoring protocols to identify a
272 suite of monitoring parameters that are appropriate for use as part of the larger Elwha
273 River dam removal monitoring efforts, as well as other dam removal efforts.

274 2. Collect data in the Elwha River basin, and other basins where appropriate, to establish
275 baseline ecosystem conditions and track regional trends that could confound the response
276 of salmon to dam removal in the Elwha River.

277 3. Develop and attempt to establish a database for use by the numerous co-managers
278 working on the Elwha River dam removal project.

279 To attain these goals we identified five general questions (see below) that improve the focus of
280 our monitoring goals (Table 1). The questions cannot be answered with one year of baseline
281 monitoring data because the focus of each one requires pre and post dam monitoring efforts.
282 Nonetheless, they are important because they help identify the types of spatial and temporal data
283 needed to begin answering the overarching question of project effectiveness. Answers to the
284 questions will also help identify the parameters and techniques that are most directly applicable
285 to assessing project effectiveness.

286 The general parameters we identified as priorities for the first year of funding included adult
287 salmon abundance and distribution, juvenile salmon abundance and distribution, and several
288 individual habitat variables including residual pool depth, streambed particle size, and stream
289 temperature. The techniques to enumerate each of these parameters included the following:

- 290 1. Adult enumeration – fish weir, SONAR, visual counts
- 291 2. Juvenile enumeration – snorkel surveys, electroshocking, seining, smolt trap
- 292 3. Habitat enumeration – quantification of individual habitat metrics using measured
293 survey data

294 We were able to accomplish the following related to the five questions:

- 295 1. What is the trend in spawner abundance?
- 296 a. Collate existing adult salmon data in the Elwha to identify data gaps and
297 degree to which adult salmon populations in the Elwha track with nearby
298 rivers.

- 299 b. Compare different techniques for enumerating Elwha populations that are
300 currently counted (Chinook and winter steelhead), and assess potential
301 techniques for species which are not currently counted.
- 302 c. Combine the available population data with population growth rates observed
303 in other colonizing populations to estimate the number of years that would be
304 necessary before a population recovery would likely be detected.
- 305 2. What is the trend in spawner spatial distribution below and above historic dam sites?
306 How does it vary by habitat type?
- 307 a. Spatially explicit identification of spawner survey locations for steelhead in
308 the Lower Elwha River using visual counts over the course of the spawning
309 season.
- 310 b. Identification and quantification of potential spawning locations in the Lower
311 and Middle Elwha River using simple, repeatable methods that are applicable
312 to other dam removal locations.
- 313 3. What is the trend in juvenile abundance by species? What is the trend in juvenile
314 spatial distribution by species?
- 315 a. First, we conducted a literature review to compare the relative tradeoffs
316 between different methods commonly used to enumerate juvenile salmonids
317 in streams, including the conditions under which each method has low and
318 high efficiency, the important factors to consider regarding fish injury, spatial
319 coverage and underwater visibility, the length of stream that can be covered
320 on a daily basis, and the number of people needed to conduct each method.
- 321 b. Second, we initiated but have not completed a comparison of several methods
322 including electroshocking, snorkeling, and seining in order to effectively
323 calculate trends in juvenile abundance and distribution by species. We initially
324 found that each method is capable of effectively estimating presence/absence
325 and species diversity across a wide range of habitat conditions. However,
326 snorkeling identified the largest number of fish and the greatest diversity of
327 fish size-classes. Based on the literature review and our initial results, multi-
328 pass electrofishing and seining seem to be most appropriate for surveying
329 short sections of smaller streams with shallow, minimally complex habitat and
330 a diverse population assemblage. Seining is most effective of all methods
331 when visibility is poor. We hypothesize that these methods, if calibrated for
332 efficiency biases such as roughness and instream cover, can effectively and
333 efficiently survey a wide array of streams and fish populations. We will
334 collect additional data in 2010 and 2011 to further answer this hypothesis.

- 335 4. What is the trend in smolts to adults by species?
- 336 a. Trend analysis of the estimated number of smolts from 2005 to 2009 for each
337 indicates there is substantial variability in timing, and total numbers between
338 year and species. Some of this is likely due to different periods of operation
339 and other across year differences in trap operation.
- 340 b. Dam removal will likely affect the trap operation. During the period of high
341 turbidity immediately after the dam removal, the trap efficiency will likely
342 change. Also, the input of large amounts of sediment and wood may
343 substantially change the current trap site requiring the location of another site.
- 344 c. Estimates of smolt production could be improved by modifying the trap or
345 site, or moving the trap to increase efficiency, and increasing or modifying the
346 releases for estimating trap efficiency.
- 347 5. How does habitat condition vary by habitat types, spatial location, and pre and post
348 dam removal?
- 349 a. We found that two parameters -- streambed particle size and residual habitat
350 depth -- are key components of spawning habitat quality and can be easily
351 measured when a known influx of sediment will occur with dam removal.
- 352 b. In the Elwha River we found that streambed particle size decreases in a
353 downstream direction below each of the dams, and decreases considerably in
354 the lower 2km of the river before entering the Strait of Juan de Fuca. The
355 decreasing trend in particle size is greater in the Lower Elwha than the Middle
356 Elwha. Residual pool depth increased in the downstream direction, however,
357 residual pool depth did decrease in the lowest portion of the Lower Elwha.
358 Spatially, residual pool depths were significantly different between the Middle
359 and Lower Elwha, but temporally for the same pools, there was not a
360 significant difference in residual depth between years.
- 361 c. Predicted percent spawnable area varied by species but was greatest in the
362 Lower Elwha, particularly in the lowest portion of the Elwha below Rkm 2.5.
363 The probability of occurrence of a site having spawnable area was greater for
364 Chinook salmon than pink salmon because Chinook can move larger
365 substrate, but at a given site there was typically a larger predicted percent
366 spawnable area for pink salmon relative to Chinook salmon because the
367 largest spawning areas were dominated by relatively small substrate.
- 368

369 **Adult enumeration – The effectiveness and application of different adult salmonid**
370 **enumeration methods**

371 Introduction

372 Restoring healthy runs of native salmon to the Elwha river is one goal of the Elwha River
373 Ecosystem and Fisheries Restoration Act (1992). While trends in juvenile and smolt abundance
374 will be important, recovery will ultimately be judged on the abundance and diversity of returning
375 adult salmon, trout, and char. This raises several questions related to the Elwha River dam
376 removal: What is the trend in adult salmon spawner abundance? What is the spawner spatial
377 distribution below and above historic dam sites? How does this vary by habitat type?

378 Enumerating adult salmon to evaluate these questions will require accurate estimates of returning
379 adults and reference or “control” adult salmon populations to reduce the likelihood of confusing
380 trends in abundance that are related to dam removal with other non-dam removal factors, such as
381 ocean conditions. Fortunately, adult salmon data is available for a number of regional rivers,
382 which allows for comparison to trends in the Elwha River salmonids within the context of larger
383 influences. Five species of Pacific salmon and steelhead currently inhabit the Elwha River.
384 However, reliable data is only available for Chinook salmon and to a lesser degree winter
385 steelhead and coho salmon. Surveys for these and other species are complicated by turbid water
386 conditions. In addition, once the dams are removed current enumeration methods based on
387 walking and floating the river will require a large increase in effort. Effective monitoring of
388 population abundance over time is therefore dependent on the development of a suite of metrics
389 and methods for enumerating adults.

390 Our objectives for enumerating and analyzing adult salmon returns are:

391 1. *Collect existing adult data*: Collate existing data for salmon populations in the Elwha
392 and other area rivers to identify data gaps and assess the degree to which populations
393 from different rivers track with each other.

394 2. *Assess enumeration techniques*: Compare different techniques for enumerating Elwha
395 populations that are currently counted (Chinook and winter steelhead), and assess
396 potential techniques for species which are not currently counted

397 3. *Implement power analysis*: Combine the available population data with population
398 growth rates observed in other colonizing populations to estimate the number of years
399 that would be necessary before a population recovery would likely be detected.

400

401 Data

402 *Existing data - Elwha River*

403 Chinook salmon is the only species for which a long term adult data set is available in the Elwha
404 River (Table 1). While sporadic sampling has occurred for other species (Table 1), turbidity and
405 high flows have generally precluded visual surveys of redds and adults. Chinook in the Elwha
406 River are enumerated by the Washington Department of Fish and Wildlife (WDFW) and the
407 Lower Elwha Klallam Tribe (LEKT) with redd counts between mid-August and mid-October.
408 WDFW personnel float from Elwha dam (RKM 8) down to the Hunt's road channel (RKM 3),
409 while the LEKT conducts foot surveys to enumerate Chinook salmon redds in the Hunt's road
410 channel. For 2009 and 2010, Chinook salmon have also been enumerated using imaging sonar in
411 the lower river (for detailed information see Appendix A). Continuous imagery of passing fish is
412 analyzed to produce independent estimates of adults passing the site (Figure 1). In addition to
413 count data, over the last several years, the GPS locations of Chinook salmon redds have been
414 recorded (Figure 2).

415 Minimal information is generally available for other species. Winter Steelhead redds have been
416 counted by the LEKT in three index reaches since 2005. However, these data have not yet been
417 used to produce escapement estimates. In 2010 NOAA personnel conducted independent redd
418 surveys, recording redd numbers and locations while floating from RKM 6 to RKM 1 (Figure 3).
419 Data on chum escapement in the Elwha is available from 1993 and 1994 when the USFWS
420 conducted live counts in conjunction with a mark recapture study. In addition, some pink
421 salmon observations were recorded during snorkel surveys for Chinook salmon in 2009.

422 *Existing data - Nearby regional rivers*

423 We examined Chinook salmon, coho salmon, and steelhead populations from three Olympic
424 Peninsula rivers (the Hoh, Queets and Quillayute rivers) to compare their trends in abundance
425 with those of the Elwha River salmon (Figure 4). According to the data, Chinook and coho
426 salmon populations displayed similar temporal trends as the Elwha River Chinook and coho
427 (Figure 4) leading to relatively high correlations (Tables 2a & 2b). However, it is important to
428 note that with the exception of the Elwha, Chinook salmon population run size estimates
429 represent terminal run size (i.e. the total size of the population including those harvested)
430 produced by WDFW using visual surveys and estimates of catch. For the Elwha Chinook salmon
431 population run size represents escapement, or those Chinook salmon that have returned which
432 were not harvested. That could have influenced the results in some way. Unlike Chinook and
433 coho, winter steelhead populations did not track as well and had only low correlations (Figure 4
434 and Table 2c).

435 To account for regional trends in Elwha Chinook data we divided the time series by the
436 geometric mean of the other three populations at each time period. This standardized the data
437 because natural variation that affects each spawning population was accounted for, and thus
438 dramatically reduced evidence of a downward trend (Figure 5).

439

440 *Data gaps – Elwha River*

441 There is little or no adult data available for Elwha populations of summer steelhead, coho
442 salmon, chum salmon, sockeye salmon, and pink salmon (Table 1). The bulk of these runs enter
443 the river during late fall and winter when high flow and turbidity often preclude visual surveys.
444 Increased turbidity predicted in the middle and lower river post dam removal will exacerbate this
445 problem.

446

447 Methods

448 Here we describe and compare three different methods that will be used to enumerate adult
449 salmonids in the Elwha River (visual methods, counting weirs, and imaging sonar) (Table 3).

450 *Visual Methods*

451 This method refers to periodic counts of observable fish and/or visible redds over the course of a
452 species specific spawning season. These are generally obtained through aerial or ground
453 surveys, although boat and snorkeling surveys can provide similar data. When whole streams
454 cannot be surveyed, which is usually the case, various sampling designs are incorporated,
455 including simple random sampling (Irvine et al. 1992) where all sections of a stream have equal
456 probability of being selected; stratified random sampling (Cochran 1977) where the stream is
457 divided into homogenous units and then randomly sampled; and stratified index sampling
458 (Bocking et al. 1988) where sites within each stratified unit are chosen based on factors such as
459 ease of access or high probability of holding fish.

460 Analysis of the count data is generally done by plotting the number of fish observed against the
461 day of the year and then “the area under the curve” is calculated using a variety of algorithms
462 (Hilborn et al. 1999). By dividing this "area under the curve" by an estimate of the stream life of
463 an individual fish or redd, a total spawning population size can be determined. Various forms of
464 this method are widely used to estimate escapement in Oregon, Washington, Alaska, and Canada
465 (e.g. Ames and Phinny 1977, English et al. 1992, and Bue et al. 1998). Surveys are generally
466 done every 7-10 days, however, the degree of uncertainty increases with the number of days
467 between surveys (Hill 1997, Bue et al. 1998). Stream life of individual fish is often derived
468 from tagging studies (English et al. 1992). An estimate of observer error is also necessary to
469 estimate variability and is often obtained from data collected at counting weirs (Shardlow et al.
470 1987; Bue et al. 1998). Ultimately, algorithms are applied to the area under the curve to
471 estimate escapement, but there are limitations because uncertainty is not accounted for in the
472 area under the curve, stream life, and observer efficiency. To remedy this, Hilborn et al. (1999)
473 devised a more universal, maximum likelihood estimator that provides for uncertainty in model
474 inputs, thus producing a less-biased escapement estimate.

475

Fish Weirs

476 Various types of weirs and counting fences are used to enumerate the upstream passage of adult
477 salmon in streams and rivers. Resistance board weirs, probably the most widely used type of
478 weir, consist of three basic parts: the substrate rail, panels which are attached to the substrate rail,
479 and a trap box for capturing the fish (Tobin 1994) (Figure 6). The substrate rail is a series of iron
480 rails attached to the bottom of the river, crossing the entire width of the river and aligned
481 perpendicular to the river flow. The panels are generally fabricated from 20 foot lengths of 1
482 inch diameter PVC tubing spaced 1 inch apart. Each panel is approximately 3 feet wide with the
483 upstream end attached to the substrate rail by a series of hooks which clasp on to a wire which is
484 run along the top of the substrate rail. A “resistance” board is attached to the downstream end of
485 each panel so the current keeps it afloat. When operational, the upstream end of each panel is
486 anchored to the stream bottom by the substrate rail, while the downstream end is kept afloat by
487 the resistance board, creating a channel spanning fence that adult fish cannot pass through. The
488 trap box is simply an aluminum box approximately 6ft. x 6ft. x 6ft. located adjacent to the bank
489 of the river that the fish are forced to enter because they cannot fit through the PVC panels. Fish
490 can then be identified, counted and released to continue their upstream migration. Weirs also
491 offer an ideal point to mark fish with different types of tags for use in mark recapture and radio-
492 telemetry studies.

493 A collaboration of NOAA/NWFSC, United States Geological Survey, The National Park
494 Service, United States Fish and Wildlife Service, WDFW and the LEKT have completed
495 construction of a resistance board weir and secured funding for the next year of its operation.
496 The weir will be installed at RKM 6 during the summer of 2010 and operate when flows are
497 predictably below 2000 cfs, or roughly between mid April and mid October.

498

SONAR

499 Single beam sonar systems have been used to enumerate fish migration in rivers since the early
500 1960’s, and similar technology is still being used today to measure escapement in a number of
501 fisheries in Alaska (Westerman and Willette 2003; Dunbar and Pfisterer 2004; Dunbar 2001,
502 2003; McKinley 2002). More recent sonar technology has greatly improved counting accuracy
503 by incorporating multiple high frequency beams, producing “movie” quality images while also
504 providing detailed data on several other fish characteristics including direction of travel, range,
505 length, and swimming speed (Belcher et al. 2001, 2002). The primary imaging sonar currently
506 used for salmon escapement estimation is the Dual-frequency IDentification SONar (DIDSON)
507 produced by Soundmetrics, although BlueView Technologies makes a comparable imaging
508 SONAR. Successful enumeration of adult salmon with imaging SONAR depends critically on
509 locating a suitable site. Important site characteristics include: 1) a method to differentiate species
510 if migration periods overlap; 2) the ability to ensonify an entire transect of the river, or at least a
511 known portion of it; and 3) directed fish movement of fish through the ensonified area without
512 milling (Banneheka et al. 1995).

513

514 Results

515 *A comparison of methods*

516 The different methods of enumerating adult salmon we have reviewed all have tradeoffs, but
517 each are appropriate for enumerating the different species and stream conditions encountered in
518 the Elwha River (Table 3). Of the three methods considered here, SONAR is the only method
519 that could potentially produce adult counts for all species. However, there are limitations. First,
520 the method is untested during winter conditions in a river the size of the Elwha. To this end, we
521 will assess the feasibility of operating the SONAR during periods of high flow during the
522 upcoming winter. Second, reading and interpreting the raw SONAR data is very time
523 consumptive. For example, 24 hours of SONAR data would require 24 hours of processing time
524 to produce raw counts, although significant subsampling is possible (Lija et al. 2008).

525 The weir will operate over a protracted period (i.e. August through October, portions of the
526 spring prior to snowmelt) and will be relatively unaffected by turbidity, which limits visual
527 surveys. Further, estimates should be very accurate and it allows for fish handling, which
528 provides opportunities for measurement, tagging, and exclusion of selected groups of fish. The
529 weir also provides an opportunity, when in operation, to calibrate SONAR counts.

530 Visual surveys of redds and adults on the spawning grounds offer a relatively inexpensive means
531 of measuring the spatial coverage of fish and if calibrated, estimating adult abundance (Figures 2
532 and 3). Such surveys are currently used by WDFW to estimate salmon escapements throughout
533 the state and will likely continued to be used in the foreseeable future. Of course, visual surveys
534 are most affected by visibility; consequently, applicability is limited to narrow windows of low
535 stream flow and turbidity. In general, these conditions are reliably met only between late July
536 after snowmelt and before the fall rains in mid October. Additional opportunities sometimes
537 present themselves during perhaps a couple of week long periods from January through mid
538 April when cold weather brings flows down and the river clears. These time periods make redd
539 surveys and snorkeling viable only for Chinook salmon and, to a certain extent, winter steelhead,
540 the two species for which these methods are already being used.

541 Finally, the relative efficacy of the different methods will be different before, during, and after
542 dam removal. Most notably, visual counts will be particularly difficult during and immediately
543 after dam removal due to turbidity, and visual methods post dam removal will require a
544 substantial increase in effort given the drastic increase in potential spawning area. Theoretically,
545 sonar and weir operation should not be affected by increased turbidity, but neither has been
546 tested in the range that is likely to be experienced during dam removal.

547 In conclusion, visual estimates are the least robust of the three methods, but are probably the
548 most cost effective and will continue to be undertaken by WDFW. The weir and sonar can be

549 effective at monitoring the complete spectrum of salmon runs on the Elwha if deployed in a
550 complimentary fashion. The weir is capable of collecting migrating salmon for counting,
551 tagging, etc. during low and medium flows, while the sonar can be used for counting during high
552 flows when the weir is not in operation.

553 A comparison of the 2008 SONAR data with the 2008 WDFW redd count estimates indicated
554 that the SONAR run size estimate of 2700 fish was more than twice WDFW's estimate of 1200
555 fish (Denton and Liermann 2009). However, SONAR data and redd surveys did agree on the
556 general run timing of the summer Chinook population in 2008. Soon after the peak of the fish
557 passage was recorded by the SONAR equipment, WDFW redd surveys also peaked, indicating
558 that Chinook began to spawn shortly after passing the SONAR site (Figure 1).

559 *How long will it take to detect an increase in adults?*

560 One primary indicator of restoration success for the Elwha dam removals will be an increase in
561 salmon population sizes. In addition to smolt and juvenile salmonid counts, adult salmon returns
562 will provide an estimate of population trends. However, natural fluctuations in the environment
563 often lead to substantial variability in population size, which can make detection of temporal
564 patterns difficult (e.g. Korman and Higgins 1997). In addition natural trends can easily be
565 misinterpreted when not compared to suitable reference populations. Here we implement a
566 simple power analysis to provide some indication of how many years of data will be necessary to
567 confidently say that adult returns are increasing. For this analysis we focus on Chinook salmon.
568 However, this approach should be applicable to other species for which adult counts are
569 obtained. The power analysis is based on simulation where a model produces thousands of time
570 trends for a given effect size, and a test for change in trend (before-after) is then applied to each
571 simulation. The proportion of simulated series for which the test rejects is the approximate
572 power.

573 The lower river population up until 2009 is assigned the observed standardized population
574 estimates, which are calculated by dividing the Elwha series by the geometric mean of the
575 Quillayute, Queets, and Hoh series (for each year). For 2010 on, the series is projected forward
576 based on the linear model fit to the log series. The upper population is seeded with 5% of the
577 lower population (strays) and allowed to grow exponentially (with yearly variability). Population
578 growth does not begin until 4 years after the first cohort could colonize the upper river (2012 + 4
579 = 2016). The exponential rate of growth is the effect size used in the analysis. There are a myriad
580 of complexities that will likely shape the population trend post dam removal that we cannot
581 include because we are unsure how the lower river population will be affected by dam removal
582 and the proportion of returning fish that will migrate upstream past the old dam locations.
583 Accordingly, we rely on a simple set of assumptions and emphasize that the results must be
584 interpreted based on these assumptions.

585 The test compares two models, a simple linear fit to the trajectory and a broken stick model,
586 where the slope is allowed to differ before and after dam removal (Figure 7). Both models are
587 applied to log values. There are no obvious non-linear trends in the standardized historical data
588 (Figure 7, for years < 2010) suggesting the linear assumption may be sufficient for the purposes
589 of this exercise.

590 For each combination of effect size and sample size (years), 1000 simulated time-series were
591 created based on the description above. The power for each combination was then estimated as
592 the proportion of simulations for which the test rejected. As expected, the probability of
593 detecting a trend in a given period of time depends critically on the rate of population growth
594 (Figure 8). Detecting an annual rate of growth of 10% in the upper river would require more than
595 20 years of monitoring while a 30% growth rate would likely be detectable in less than 10 years.
596 Again, these results are dependent on the model assumptions used for the simulations.

597 To provide context for these results, we examined population trajectories for various
598 colonizations (Figure 9). We found that annual growth rates varied from 10% to 100% (1.1 to
599 2.0) (Table 4). Given the general condition of regional Chinook populations and the longer
600 generation time, we might expect the rate of growth to fall towards the lower end of this range.
601 Also, simple exponential growth rate does not sufficiently capture the complexity of possible
602 population trajectories as new habitat becomes accessible. For example, both the Glacier Bay
603 and South Fork Skykomish River Pink populations remained at very low levels for an extended
604 period of time before making substantive gains (Figure 9).

605 Discussion

606 *Recommendations of protocol and pre-dam conclusions*

607 A relatively robust data set exists for adult salmon from other rivers in the same region as the
608 Elwha. On the other hand, data for adult salmon in the Elwha River is rather lacking.
609 Nevertheless, long term estimates do exist for Chinook salmon and on a shorter time scale for
610 winter steelhead. In order to accurately gauge the effect of dam removal on adult salmon
611 production it is essential that we not only maintain the current adult salmon enumeration
612 activities on the Elwha, but make them more robust and expand them to other species.

613 The bulk of the information that currently exists on adult salmon populations in the Elwha River
614 have been derived from redd surveys. While this method is used extensively and has been
615 demonstrated to provide accurate estimates for salmonids (Gallagher and Gallagher 2005,
616 Mulfield et al. 2006), due to limited visibility during much of the year, it is impractical for three
617 of the five species of salmon and steelhead. In addition, visibility during and immediately after
618 dam removal will almost certainly be worse, and access to the expansive upper watershed will be
619 difficult. We therefore recommend augmenting visual surveys with alternate enumeration
620 methods such as the weir and imaging SONAR. While neither of these methods has been tested
621 across seasons in the Elwha, they have been effectively used at other sites (e.g. Holmes et. al.

622 2006, Hoffnagle et al. 2008). In addition the weir and sonar have the potential to be
623 complimentary. When the weir is installed in the summer or fall of this year we will assess the
624 feasibility of affixing different imaging SONARs to the weir to obtain fish counts. For periods
625 when both the weir and sonar are operating we will be able to validate the species specific sonar.
626 When high flows preclude operating the weir for large periods of time from late fall to spring,
627 the sonar can used to estimate passage past the site. Higher flows will still pose a challenge for
628 the SONAR, reducing image quality, increasing the cross river distance, and exposing the
629 hardware to damage from debris. However, other options are limited, and the weir infrastructure
630 that will remain in the river throughout the year should provide a number of good options for
631 affixing the sonar. While species identification in the sonar imagery is not as easy as visual
632 methods, there are a number of characteristics that can be used for differentiation. Fish length,
633 behavior, and time past the sonar can all be used to parameterize models for assigning species.
634 We are currently developing a mixture model and testing it on SONAR imagery from another
635 local river. The mixture modeling approach has been successful in other SONAR applications
636 (Fleischman and Burwen 2003).

637 Regardless of how adult counts are obtained, detecting an increasing trend in adult numbers in
638 response to dam removal will require some time and may be complicated by other environmental
639 factors, such as ocean conditions. These environmental signals also form trends (e.g. decadal
640 scale oscillations), which makes discerning trends in recovery from environmental trends
641 challenging. Fortunately, two local populations (Chinook and coho in the Hoh, Quillayute, and
642 Queets Rivers) all track the Elwha population well. This provides a reference with which Elwha
643 trends can be interpreted. Based on a preliminary power analysis for summer Chinook salmon in
644 the Elwha River, we estimate that detecting an increasing trend could require from several years
645 to over 30 years depending on the rate of population growth in the upper river.

646

647 **Juvenile enumeration - The effectiveness and application of different juvenile salmonid**
648 **enumeration methods**

649 Monitoring juvenile salmonids in the Elwha River basin is important for assessing the
650 recolonization of anadromous salmonids after dam removal. The main question for juvenile
651 salmon in the Elwha River is what is the temporal and spatial distribution trend in juvenile
652 abundance by species? Our monitoring objectives focus on five juvenile salmonid metrics,
653 including presence/absence, species diversity, abundance, and distribution (McHenry and Pess
654 2008). Observing and counting juveniles to generate these metrics will be challenging for two
655 reasons. First, stream conditions are highly variable in the mainstem Elwha River and its
656 tributaries, and after dam removal pulses of sediment stored behind the dams are expected to
657 further decrease already limited visibility in the mainstem Elwha River (McHenry and Pess
658 2008). Second, the expected rare and/or patchy distribution of salmonids during the initial stages
659 of recolonization will require methods that are effective for intensive sampling of discrete areas
660 and continuous sampling of long stretches of stream. Accomplishing our quantitative objectives
661 will thus require utilizing a suite of enumeration methods to account for the environmental and
662 biological variability.

663 Several methods have been developed for enumerating juvenile salmonids in freshwater stream
664 habitats. Methods we could use include backpack electrofishing (hereafter referred to as
665 'electrofishing': Rosenberger and Dunham 2005), snorkeling (Hankin and Reeves 1988) and
666 seining (Gries and Letcher 2002). Each method is capable of generating all of the juvenile
667 metrics. However, there are differences in their effectiveness (e.g., accuracy and bias of the fish
668 counts) and physical constraints. For example, electrofishing can be used when stream visibility
669 is poor (Reynolds 1996), and it can be a more accurate method for estimating juvenile abundance
670 because there is less species-specific bias relative to snorkeling (Rogers et al. 1992). However,
671 its effectiveness decreases with increasing stream size and levels of instream cover (Peterson et
672 al. 2004; Rosenberger and Dunham 2005), it is time consuming and inefficient over long
673 stretches of stream (Hankin and Reeves 1988) and can cause injuries to juvenile salmonids
674 (Nielsen 1998). In contrast, snorkeling is an effective alternative to electrofishing in small and
675 large streams, it minimizes impacts to fish, and allows for the efficient coverage of extensive
676 lengths of stream (Thurow 1994). Nonetheless, snorkel counts are limited to times and places
677 with good water clarity (Thurow 1994), the counts can be less accurate in some situations
678 (Rogers et al. 1992), and observer biases can be high (Hankin and Reeves 1988).

679 Here we first review the factors influencing the effectiveness of each method and how to
680 compensate for different biases. This will allow us to identify the most reliable methods for
681 enumerating juvenile salmonids in differing physical and biological conditions. Next, we
682 compared snorkeling, electroshocking, and seining in one side channel of the Lower Elwha River
683 as a pilot project to quantify the ability of each method to enumerate juvenile salmonids. Our
684 goal is again to apply monitoring techniques consistently pre and post dam removal because
685 changing techniques may confound evaluation of the effects of the dam removal. Thus collecting

686 information that will help us validate different techniques juvenile salmon abundance techniques
687 will be critical in our evaluation of fish response. Lastly we analyze and discuss smolt
688 enumeration in the Elwha River and provide estimates of fresh water production (i.e. number of
689 smolts per number of spawners) over time. Smolt outmigration data will help to answer one of
690 the main questions we pose in our Elwha River monitoring effort – what is the trend in smolts to
691 adults by species?

692

693 A comparison of electroshocking, snorkeling, and seining through literature review

694 *Electrofishing*

695 Electrofishing is one of the most widely used methods for enumerating fish (Reynolds 1996). Its
696 effectiveness is defined in terms of capture efficiency: the probability of capturing an individual
697 fish (Peterson et al. 2004). Capture efficiencies for stream-dwelling juvenile salmonids can
698 range from 25% - 100% (Riley and Fausch 1992; Kruse et al. 1998; Peterson et al. 2004) and is
699 influenced by four major factors. First, capture efficiency decreases at low stream conductivity
700 levels ($< 20 \mu\text{S}/\text{cm}$), essentially eliminating electrofishing as an option, and can be harmful to
701 fish at higher levels ($350 \mu\text{S}/\text{cm}$; Reynolds 1996). Second, capture efficiencies decrease with
702 increasing stream size and levels of instream wood or boulders because fish using cover are less
703 likely to be captured than those that are not using cover. This can lead to underestimations of the
704 population size due to overestimated capture efficiency (Rodgers et al. 1992; Rosenberger and
705 Dunham 2005). Third, the efficiency is often higher with larger fish and lesser with smaller fish
706 (Peterson et al. 2004; Korman et al. 2002). Lastly, particular species are more susceptible to
707 being captured than other species because of behavioral differences (e.g., bull trout are more
708 difficult to catch because they often hide in the substrate: Peterson et al. 2004; Peterson et al.
709 2005).

710 Electrofishing biases can be accounted for in different ways. If the goal is to estimate abundance
711 or population size, biases can be reduced to some degree by increasing the number of passes
712 made with an electrofisher (Rosenberger and Dunham 2005). Biases can also be reduced by
713 modeling capture efficiency as a function of different levels of effort, stream width, substrate
714 size, and levels of instream wood or cutbanks (Peterson et al. 2004; Rosenberger and Dunham
715 2005). Such models can calibrate statistical estimates and narrow confidence intervals. If
716 calibration is not possible, then mark-recapture is perhaps the best way to compensate for stream
717 complexity (Rodgers et al. 1992; Rosenberger and Dunham 2005). Accounting for differences in
718 fish is more challenging, and it may not be possible to compensate for efficiency differences
719 related to fish size and species (Peterson et al. 2004). However, if the interest is only in
720 describing species composition then single- pass electrofishing may be adequate (Reid et al.
721 2009) as long as the lengths of sampling sections increases proportionally with increasing stream
722 size (Cao et al. 2001). Single-pass electrofishing may even be able to provide reasonable
723 estimates of abundance if cover is sparse (Kruse et al. 1998). These results indicate that
724 statistical and physical means of compensating for electrofishing biases are effective up to a

725 particular stream size (~ 15 - 20 m wetted width), beyond which electrofishing becomes less
726 reliable. Without accounting for the effects of physical habitat on capture efficiency, systematic
727 errors may be induced that limit the reliability of the data (Peterson et al. 2004).

728 *Snorkeling*

729 Snorkel effectiveness is measured in terms of observer error, which is due to variation from
730 direct over- or under-counting of target species (Hankin and Reeves 1988). Because underwater
731 counts can include multiple snorkelers, there is also inter-observer error, which is the variation in
732 fish counts between two or more snorkelers (Thurow 1994). Like electrofishing, the ability of a
733 diver(s) to accurately and precisely count juvenile salmonids is influenced by a range of factors.

734 Because snorkeling is visual, the most important factor influencing observer error is underwater
735 visibility, but stream depth and water temperature also play critical roles (Thurow 1994). For
736 example, James and Baxter (2005) found that visibility explained 62% of the variation in their
737 rainbow trout estimates. Additionally, snorkel surveys are generally ineffective at water depths <
738 0.3 m because divers are unable to fully immerse their mask (Thurow 1994). Further, drastic
739 undercounting of juvenile salmonids often occurs when water temperatures drop below 9°C -
740 10°C because they seek cover and become nocturnal (Roni and Fayram 2000), although one
741 study reported night counts of larger-sized trout being greater at night than during the day in the
742 summer when temperatures were relatively optimal (Grost and Prendergast 1999). The
743 abundance and species of fish are also important. Hillman et al. (1992) found that over 90% of
744 juvenile salmon were counted and identified correctly in clusters of fewer than 40 fish, but coho
745 and Chinook salmon were undercounted by 50% or more if they resided in mixed groups of more
746 than 40 fish. Among species, juvenile steelhead (Rodgers et al. 1992) and bull trout (Thurow et
747 al. 2006) can be more difficult to count than other species because they tend to flee from the
748 diver rather than approach like juvenile salmon. Lastly, and unrelated to environment, adequate
749 training is necessary to ensure snorkelers are accurate and efficient at identifying and counting
750 target species (Thompson and Mapstone 1997).

751 A variety of guidelines exist to reduce the biases in observer error if the objective is to estimate
752 relative abundance, distribution, or presence/absence. First, in wadeable sized streams (up to 15
753 - 20 m bankfull width) the diver should be able to see bank-to-bank and avoid trying to survey
754 shallow water areas less than 0.3 m in depth (Thurow 1994). In larger rivers (> 20 m wetted
755 width) underwater visibility should be at least 3 - 4 m with multiple divers spaced evenly across
756 the river according to the extent of visibility (Schill and Griffith 1984; Thurow 1994).
757 Accounting for complex cover and species that flee from the diver, such as juvenile steelhead,
758 can be done with bounded counts, which consists of three successive but separate counts of the
759 same habitat unit (Hankin 1984) or by calibrating single-pass counts with electrofishing (Hankin
760 and Reeves 1988). The counts quantify variance in observer error and can provide confidence
761 intervals for abundance estimates. Mark-resight can also be used in challenging environments to
762 quantify variance and to generate confidence intervals for population estimates (Young and

763 Hayes 2001; Korman et al. 2002). At minimum, some level of calibration for complex cover
764 seems warranted and block nets may be required if fish consistently flee (Thurow et al. 2006).
765 Finally, snorkel surveys must be conducted at night when water temperatures are below 10°C to
766 compensate for changes in fish behavior (Roni and Fayram 2000).

767 *Seining*

768 Seining effectiveness is measured in terms of capture efficiency, which is defined as the product
769 of encirclement efficiency when laying the net and retention efficiency while hauling in the net
770 (Bayely and Herendeen 2000). Unlike electrofishing and snorkeling I found relatively little
771 information on the effectiveness of seining for generating juvenile salmonid abundance and
772 population metrics in streams. The literature that is available suggests that seining capture
773 efficiency is affected by most of the factors that influence electrofishing, except for visibility.
774 For example, stream sites with irregular bottom topography, fast currents and deep water,
775 significant accumulations of debris or larger rocks, or dense stands of aquatic vegetation may not
776 be suitable for seining due to net snagging or lifting and reduced fish retention (Hahn et al.
777 2002). However, seining is also effective when stream visibility is poor, while electrofishing and
778 snorkeling are not. Net design can also influence capture efficiency. Fish behavior and species
779 can also influence capture efficiency. Species that associate with the bottom (epibenthic) and
780 with complex habitat (vegetation, rocks, wood) are generally more difficult to capture with
781 seines than are fish that are pelagic or epipelagic (Murphy and Willis 1996) and seining may
782 have to be conducted at night if fish become nocturnal (Gries and Letcher 2002).

783 It is possible to compensate for some, but not all, of the factors that limit seining capture
784 efficiency. For example, without modifying stream habitat, the capture efficiency of seining will
785 suffer in places with complex cover and greater depths (Hahn et al. 2002). Consequently, it may
786 not be possible to generate estimates of relative abundance or population size in such
787 circumstances (Rozas and Minello 1997; Bayely and Herendeen 2000). This is one reason why
788 seining is more common in saltwater and lake environments where smooth bottom beaches and
789 lack of instream cover do not snag or impede the seine (Murphy and Willis 1996). Slight
790 compensation for complex cover can be made by conducting multiple passes with the seine,
791 having a snorkeler observe sein and fish action, and/or modifying instream habitat (Hahn et al.
792 2002). While limited, in the appropriate places a single seine haul can be an effective estimator
793 of species richness (diversity index), species rank, and the size distribution (Hayes et al. 1996). If
794 water temperatures are cold and fish are nocturnal, seining must be conducted at night (Gries and
795 Letcher 2002). If fish are associated with substrate or particularly spooky, then the speed of the
796 seining activity can be increased (Hahn et al. 2002).

797 *Results from the literature*

798 Several studies have compared the relative effectiveness of electrofishing and snorkeling for
799 enumerating juvenile salmonids in freshwater streams (e.g., Hankin and Reeves 1988; Rodgers et

800 Hayes, 2001), while fewer studies have done the same for electrofishing, snorkeling, and seining
801 (e.g., Gries and Letcher 2002; Esin 2009). The results of those studies combined with this
802 review suggest that each method has different tradeoffs and applications for enumerating
803 juvenile salmonids. Here I briefly delineate the applicability of each method for achieving
804 different quantitative objectives.

805 Each of the three methods is adequate for determining presence/absence and estimating species
806 composition. Among them, snorkeling seems to offer the best balance of effectiveness and
807 efficiency because it does not cause injury to fish, is relatively cheap, uses a smaller crew of
808 people, and it allows people to cover 1 - 2 km of stream per day, which is a substantially greater
809 length of stream than can be covered on a daily basis with electrofishing or seining (Table 5:
810 Hankin and Reeves 1988; Dolloff et al. 1996). However, if there is a need to capture or
811 accurately measure fish as part of the objective, electrofishing or seining would be the only
812 choices (Reynolds 1996; Hahn et al. 2002).

813 If the goal is to quantify population size then mark-recapture electrofishing (Roseberger and
814 Dunham 2005), mark-resight snorkeling (Young and Hayes 2001), snorkel counts calibrated with
815 electrofishing (Hankin and Reeves 1988), and mark-recapture seining may all be used. On the
816 other hand, there are a number of tradeoffs to consider when choosing a method to estimate
817 relative abundance. We begin with tradeoffs related to stream size, cover, visibility, and spatial
818 coverage. Day (Hankin and Reeves 1988; Hillman et al. 1992) and night snorkel surveys (Roni
819 and Fayram 2000), and seining (Esin 2009) can be equally effective as multi-pass electrofishing
820 for estimating relative abundance and population size for juvenile salmonids (Table 5).
821 Considering this, multi-pass electrofishing (Reynolds 1996) and seining (Hahn et al. 2002) are
822 applicable to covering short distances of stream per day (< 0.5 km) in smaller-sized streams (<
823 15 m wetted width) with minimal cover and relatively shallow depths (< 1 m). They are also the
824 only alternatives when underwater visibility is limited. On the other hand, snorkeling is
825 applicable across a broader range of stream-sizes and depths and allows for greater spatial
826 coverage, but can be ineffective in particularly shallow streams (< 0.3m) with large substrate
827 (Hankin and Reeves 1988; Thurow 1994; Dolloff et al. 1996).

828 The applicability of different methods for estimating abundance can also be influenced by fish
829 size and species (Table 5). For example, although there does not appear to be a species-specific
830 bias with electrofishing, the method can be more effective for larger juveniles (> 50 - 60 mm:
831 Peterson et al. 2004; Korman et al. 2009). Seining can be ineffective for sampling benthic-
832 oriented species (Jordan et al. 2008) and may miss smaller juveniles (< 60 mm length) (Gries and
833 Letcher 2002). Outside of those effects, there does not appear to be a direct species-specific bias
834 with electrofishing (Rodgers et al. 1992) or seining (Esin 2009), but it is possible that differences
835 in behavior (e.g., hiding in substrate) can result in species-specific biases (Peterson et al. 2004).
836 In contrast with electrofishing, snorkeling may result in underestimation of smaller fish (Joyce
837 and Hubert 2003) that rely on shallow channel margins. There may also be species differences in
838 effectiveness. While studies have found that snorkeling can effectively count juvenile steelhead

839 and cutthroat (Hankin and Reeves 1988; Roni and Fayram 2000; Joyce and Hubert 2003), a
840 study in Oregon found that snorkeling was a poor method for counting juvenile steelhead
841 because those fish tended to flee from the diver (Rodgers et al. 1992).

842 *Recommendations of protocol and pre-dam conclusions*

843 Overall, the combined considerations of stream habitat and fish size and species suggest there are
844 four different patterns of applicability for electrofishing, snorkeling, and seining from the
845 literature.

846 1. First, each method is capable of effectively estimating presence/absence and species
847 diversity across a wide range of conditions.

848 2. Second, electrofishing and seining are the only options when underwater visibility is
849 poor, but if turbidity is too high, seining is the only option.

850 3. Third, if the objective is to enumerate fish over long stretches of small to large streams
851 with deeper, more complex habitat to identify associations between a few species and
852 river habitat the reach or section scale, snorkeling provides the best balance of
853 effectiveness and efficiency.

854 4. Fourth, multi-pass electrofishing is most appropriate for surveying short sections of
855 small streams with shallow, minimally complex habitat and a diverse population
856 assemblage.

857 5. These methods, if calibrated for efficiency biases such as instream cover, can
858 effectively and efficiently survey a wide array of streams and fish populations.

859

860 A comparison of electroshocking, snorkeling, and seining in the Elwha River

861 *Methods*

862 We compared snorkeling, electroshocking, and seining in one side channel of the Lower Elwha
863 River as a pilot project to quantify the ability of each method to enumerate juvenile salmonids.
864 We sampled six habitat units in the lowermost side channel of the mainstem river just prior to
865 where it enters the Strait of Juan De Fuca. First we identified the beginning and end of each
866 habitat unit and measured several attributes including habitat unit length, width, maximum depth,
867 residual depth, the amount of instream channel cover, the amount of cutbank, and the average
868 cutbank depth (Table 6). We then identified the “sample ability” of a given unit for each of the
869 different samples methods (Figure 10). The “sample ability” is based on a scale of one to five,
870 with one representing a habitat unit with the lowest sample efficiency (i.e., most difficult to
871 sample) and five the highest. The “sample ability” rating was based on factors known to

872 influence sampling efficiency, including habitat depth, the amount of instream cover, habitat
873 “roughness”, and the overall habitat morphology (i.e. habitat length to stream depth ratio).

874

875 After determining the sample ability, we first sampled each unit by snorkeling. One to two
876 snorkelers, depending upon the size of the unit snorkeled in an upstream direction using a single
877 pass approach. Snorkelers identified delineated each fish by species (i.e. coho,
878 rainbow/steelhead, Chinook, sculpin, stickleback, other) and size class (i.e. 0 to 50mm, 50 to
879 100mm, 100 to 150mm, 150 to 200mm, and greater than 200mm). We then waited 1 hour before
880 going back to the same unit to electroshock. We did this because we hypothesized that fish were
881 redistributed once the snorkelers went through and would resume their original positions prior to
882 snorkeling. We then repeated the sampling of units with three-pass electrofishing. Captured fish
883 from each pass were placed into 5 gallon buckets, identified to species and fork length was
884 measured. After completing three-passes all fish were returned to the habitat unit. Lastly we
885 waited 24 hours and returned to each of the habitat units to seine. We again used three passes and
886 removed and retained fish to identify species and measure length. All fish were returned to the
887 same habitat unit they were sampled from after the third pass. We also quantified how long each
888 method took for a given habitat unit (Table 7).

889

890 *Results*

891 The results of our sampling revealed some clear patterns. First, we found that snorkel counts
892 were 2 to 4 times greater than either electroshocking or seining in the same habitat units (Figure
893 11). Second, seining captured a higher proportion of juvenile Chinook relative to
894 electroshocking, while seining and electrofishing captured similar numbers of juvenile coho and
895 rainbow/steelhead (Figure 12a, b, and c). Third, snorkeling took 3 times less time (± 0.8) than
896 electroshocking and seining, which both required a similar level of time for sampling (Table 7).
897 Fourth, as the ability to sample with electroshocking or seining increased, the difference between
898 the number of fish identified during snorkeling and the other techniques decreased (Figure 13).
899 Conversely, as the ability to sample with either electroshocking or seining decreased (i.e. a
900 smaller number), the greater the difference between the number of fish identified during
901 snorkeling. Thus if the sample ability number is small for electroshocking or seining, then the
902 ability to compare those methods to snorkeling decreases (Figure 13). Lastly, despite differences
903 in numbers of fish captured, the size distributions of each species were similar for all methods
904 (Figure 14a,b, and c).

905

906 *Recommendations of protocol and pre-dam conclusions*

907 When we compare these pilot results to our literature review we find the following:

- 908 1 While each method is capable of effectively estimating presence/absence and species
909 diversity across a wide range of conditions, snorkeling identifies the largest number of
910 fish and the greatest diversity of fish size.

911 2 Multi-pass electrofishing and seining are most appropriate for surveying short sections of
912 small streams with shallow, minimally complex habitat and a diverse population
913 assemblage. Seining is most effective of all methods when visibility is poor. These
914 methods, if calibrated for efficiency biases such as roughness and instream cover, can
915 effectively and efficiently survey a wide array of streams and fish populations.
916

917 Smolt analysis of existing data from the Elwha River

918 *Introduction*

919

920 Enumerating smolts as they exit the Elwha river will provides estimates of fresh water
921 production (i.e. number of smolts per number of spawners), as well as the timing and size
922 distribution of juvenile salmon at entry into the marine environment. In the Elwha this will help
923 to answer one of the main questions we pose in our monitoring effort – what is the trend in
924 smolts to adults by species? In addition, the smolt trap information will provide a useful index of
925 juvenile salmonid population size for all species, including those that are not readily counted at
926 the adult stage (i.e. chum salmon, pink salmon, and coho salmon). We describe the current smolt
927 trapping program in the Elwha River and ways that it could be improved. We also present Elwha
928 River smolt data collected to date, and illustrate the technique used to expand raw catch data to
929 estimates of total out migrants for several Elwha River salmonid species.
930

931 *Methods*

932

933 The Elwha screw trap

934

935 The Lower Elwha Klallam Tribe has operated an 8' rotary screw from 2005 to the present¹. Trap
936 operation has evolved substantially over this period in response to the cumulative experience
937 operating at this site. The trap is fished continuously from late February or early March until mid
938 June when the state hatchery releases approximately 3.5 million fingerling Chinook salmon
939 smolts. Operation beyond this point is not feasible due to the effort necessary to deal with the
940 hatchery Chinook salmon caught in the trap. The trap is located below all side channels that are
941 active during the trapping season (approximately RM 1.0). The trap is typically checked twice a
942 day. On each of these occasions the following procedure is used:

- 943 1. All of the fish are removed from a collection box and tallied by species, origin, and mark.
- 944 2. Any fish that were marked for efficiency estimates (Bismark brown mark) are counted.
- 945 3. Revolutions per minute (RPM) of the trap, depth, visibility, and flow are also measured.

946

947 Estimating efficiency

948

1 ¹ In 2007 the 8' trap was not operated due to a fatal car accident close to the trap site. A smaller 5' trap was fished
2 for part of the season.

949 Because the screw trap only captures a small proportion of all the juvenile salmon fish moving
950 out of the river, in order to estimate the total number of out migrants, the proportion captured (or
951 trap efficiency) needs to be estimated. The general approach is to release marked fish above the
952 trap and record the proportion captured in the trap. For the Elwha trap, multiple groups of 1000
953 Bismark brown marked chum smolts are released during the period of trap operation. Chum
954 smolts were used predominantly due to their availability and similarity in size to Chinook 0+ and
955 pink smolts. The periods between releases are assumed to be large enough that the vast majority
956 of fish from one release group will have passed the trap site before the next release. In the first
957 several years of trap operation attempts were made to estimate efficiency for yearling smolts.
958 However, very few fish were recaptured, and these efforts were abandoned. Total out migrants
959 are there for not estimated for the yearling smolts (coho, Chinook 1+, and steelhead). Difficulty
960 recapturing yearling smolts is common when operating screw traps in large rivers since they are
961 able to actively avoid the trap. It is also difficult to acquire large numbers of yearly smolts to
962 mark, thus estimating trap efficiency for these fish is intrinsically difficult.

963

964 Estimating total out migrants for Chinook 0+, pink, and chum smolts

965

966 For “young of the year” Chinook (0+), pink, and chum smolts the total out migrant numbers are
967 estimated by adjusting for trapping effort and efficiency. Here we describe the steps used to
968 construct these estimates and use Chinook 0+ in 2009 as an example. The two steps are adjusting
969 for trapping effort and expanding the catch based on efficiency.

970

971 Adjusting for trapping effort

972

973 The goal is to operate the trap continuously. However, many difficulties intrinsic to screw trap
974 operation result in periods when data is not collected (for example, large wood can jam the
975 screw). When the disruption is less than a day, then the proportion of total hours fished during
976 that day can be used to expand the catch. However, when entire days are missing, another
977 approach is necessary. For the latter case we use a simple non-linear (loess) model fit to the
978 available data, to interpolate (Figure 15, top panel). Because there are very few missing days we
979 do not take uncertainty into account in this step.

980

981 Expanding catch based on efficiency estimates

982

983 Once there are catch values for all days during the trapping period, the catches are expanded to
984 estimates of total out migrants using efficiency estimates (Figure 15, middle and lower panels).
985 We used the modified Peterson estimator (e.g. see Carlson et al. 1998):

986

$$U_i = u_i \frac{(M_i + 1)}{(m_i + 1)}$$

987

988

989 Here U_i is the total estimated out migrants, u_i is the catch, M_i is the total released, m_i is the
990 recaptured marked fish, and i is the period. We used the variance estimator (Carlson et al. 1998,
991 Volkhardt et al. 2007):
992

$$\text{var}(U_i) = u_i \frac{(M_i + 1)(u_i + m_i + 1)(M_i - m_i)}{(m_i + 1)^2(m_i + 2)}$$

993
994 Efficiency is applied to the recapture periods for specific release events resulting in varying
995 efficiency across time (Figure 1 middle panel, see below for details). The sum of all expanded
996 catches is then used as an estimate of total out migrants. The total variance is also just the sum of
997 variances across periods. Confidence intervals (95%) are calculated as +/- 1.96 times the square
998 root of the variance. While the variance estimates provide a useful measure of uncertainty, they
999 are likely underestimates for a several reasons:
1000

- 1001 - The recapture rates likely do not follow a binomial distribution; instead they are likely to be
1002 over dispersed.
- 1003 - Separate marks are not used for each release group, thus fish will occasionally be assigned to
1004 the wrong release.
- 1005 - The chum release groups do not exactly mimic other down stream migrating species such as
1006 pink salmon and Chinook salmon.
- 1007 - Fish are released during the day, which may result in downstream movement during the day
1008 as opposed to night.
- 1009 - Lastly efficiency is changing continuously but assumed to remain the same for multi day
1010 periods.

1011 1012 *Results*

1013 1014 The current smolt data 1015

1016 A total of 54,000 fish were captured and processed in the screw trap between 2005 and 2009
1017 (Tables 8 and 9). Combining these raw catch data with effort (hours per day fished), and
1018 efficiency produced estimates of total outmigrants (Figure 16). There is substantial variability in
1019 timing, and total numbers between year and species (Figure 17). Some of this is likely due to
1020 different periods of operation and other across year differences in trap operation. For example
1021 during 2005 and 2006, trapping didn't begin until mid March before which a substantial portion
1022 of the Chinook outmigrants had passed in previous years. In addition, the methodology for
1023 measuring efficiency changed across years. For fish with larger smolts (coho 1+, Chin 1+, and
1024 steelhead), the trap efficiency was extremely poor and only the raw catch is reported (Figure 18).
1025 Again, the numbers vary substantially by species and year, with only a few dozen fish total for
1026 some year species combinations. Catch provides some indication of out migrant timing however
1027 the trap efficiency certainly changes over time suggesting cautious interpretation.
1028

1029 *Discussion*

1030 Recommendations of protocol and pre-dam conclusions

1031 Dam removal will likely affect the trap operation. During the period of high turbidity
1032 immediately after the dam removal, the trap efficiency will likely change. Also, the input of large
1033 amounts of sediment and wood may substantially change the current trap site requiring the
1034 location of another site. Estimates of smolt production could be improved include:

- 1035 1. Modifying the trap or site, or moving the trap. There are very few feasible trap sites
1036 below the spawning grounds. However, adjustments in trap location or modification of
1037 the current site may lead to increased efficiency.
- 1038 2. Increasing and modifying the releases for estimating efficiency. Current releases are
1039 during the day, while night releases are generally recommended. In addition chum smolts
1040 are currently used for efficiency estimates for all Chinook 0+, chum and pink smolts.
1041 More work could be done to determine if this is appropriate. Also, a renewed effort to
1042 estimate efficiency for yearling smolts could allow for out migrant estimates for these
1043 fish (Chinook 1+, coho, and steelhead).
- 1044 3. Adding another screw trap, using a different screw trap, or modify the current trap.
1045

1046 **Habitat - How does spawning habitat quantity and quality vary by habitat type, spatial**
1047 **location, and pre and post dam removal?**

1048 Introduction

1049 One of the major questions we will attempt to answer with the Elwha River dam removals is how
1050 does habitat condition vary by habitat types, spatial location, and pre and post dam removal? Our
1051 initial baseline monitoring focused on a specific aspect of this question which is how does
1052 spawning habitat quantity and quality vary by habitat type, spatial location, and pre and post dam
1053 removal? Based on a literature review we identified two stream habitat metrics that are
1054 relatively simple to measure and can effectively convey long-term changes in habitat quality due
1055 to Elwha River dam removal: residual pool depth (maximum – minimum depth) and stream bed
1056 particle size distribution in adjacent riffle crests. Changes in the depth of pool habitats and
1057 streambed particle size are likely in the main stem river habitats because of the influx of
1058 sediment that will occur with dam removal. Measures of pool depth and particle size will provide
1059 estimates of habitat quality and quantity, in addition to a better understanding of how dam
1060 removal affects one main life stage for all salmonids -- spawning. Our hypothesis is that the
1061 influx of sediment to the Middle and Lower Elwha will initially result in changes to pool depth
1062 and dimensions because it is expected that most new sediment will be small in size (e.g., fines)
1063 (DOI 1996). As the stream channel changes and eventually reaches equilibrium following dam
1064 removal, larger sediment in the form of gravels and cobbles will make its way downstream and
1065 start to affect deep water areas such as pools, where salmonids often stage, and riffle areas where
1066 salmonids tend to spawn. Capturing changes in the stream channel structure will thus be
1067 important to the availability of salmon holding and spawning habitat post dam removal.

1068

1069 We relate pool depth and streambed particle size measurements to salmonids in two ways in the
1070 lower and middle Elwha River. First, we calculated the percent spawnable riffle area to predict
1071 current and future spawning areas. Salmonids select spawning areas largely because of gravel
1072 size (Quinn 2005), so we hypothesize that it is likely to predict their distribution based on our
1073 substrate measurements. Second, we calculated the amount of pool habitat available for staging
1074 of pre-spawn salmonids. Holding pools are a critical habitat for many spawning salmonids, and
1075 pool filling is likely to be the most obvious effect of sediment release after dam removal.
1076 Repeated surveys of thalweg profiles or channel cross sections can indicate changes in bed
1077 elevation variability (Madej 1999), but these methods are expensive and yield little information
1078 directly relevant to holding pools or spawning habitat. Measurement of residual pool filling is a
1079 direct measure of changes in holding habitat quality, but the method is relatively time consuming
1080 to apply over a large area. Measuring changes in number of pools or residual pool depth is more
1081 efficient than other techniques because surveys can be conducted rapidly (Madej 1999), and the
1082 information obtained is a direct measure of holding habitat availability and quality.

1083

1084 Methods

1085 *Residual pool depth and streambed particle size*

1086 We implemented a simple approach that attempts to quantify the depth of pool habitat and the
1087 streambed particle composition of the front of gravel bars also known as “full spanning” riffles
1088 in the Middle and Lower Elwha. A full spanning riffle is a riffle crest that spans the entire wetted
1089 width of the stream at the time of sampling prior to fall salmon spawning. Full spanning riffles
1090 are typically associated with front end of large, transverse gravel bars (Lisle 1982).
1091

1092 To capture the change in pool depth we utilized a proven method that quantifies the residual pool
1093 depth of each main stem pool in the Middle and Lower Elwha (Figure 19). We recorded the
1094 longitude and latitude with a GPS and measured the area and residual depth (maximum depth –
1095 tail out depth, Figure 19) of each pool in accessible mainstem reaches.
1096

1097 We measured streambed particle size at every full spanning riffle in the Middle and Lower
1098 Elwha. These riffles were typically located in the tail out portion of the pools where depth was
1099 measured. The extent of the riffle crest was determined by creating two transects -- one upstream
1100 and one downstream -- at a point where the water was 0.2m deeper than the minimum riffle crest
1101 depth. Total riffle area was then measured. Pebble counts (100 particles measured along the B
1102 axis of a rock) were conducted on each transect because salmon spawning is hypothesized to
1103 occur in those locations. Pebble counts quantify the substrate within a given area and include the
1104 distribution of streambed particle sizes. Data collected at each site included location, widths,
1105 depths, and particle size distribution (Table 10). We assume that pebble counts and residual pool
1106 depths will be sensitive enough to the changes in particle size and depth to capture the change
1107 due to the anticipated large-scale change in sediment supply from dam removal.
1108

1109 *Data analysis*

1110 We compared 2009 residual pool depths to previous data collection efforts (2000) to gain an
1111 understanding of the variation in individual pool depth prior to dam removal. We also examined
1112 the cumulative distribution of pool depths using the Kolmogorov–Smirnov statistic. In addition
1113 we compared the within year variation between sites at the reach (Middle Elwha, Lower Elwha)
1114 and site (upstream v. downstream side of riffle crests) scale.
1115

1116 Even though we have previous years data, the pebble count locations were not in similar habitats
1117 among years, so it was only possible to compare the within year variation between sites at the
1118 reach and site scale. We used tests such as the mean particle size (D50), the variation (ratio of
1119 D84 to D16), and cumulative distribution functions at the site and reach scale.
1120

1121 *Linking data to fish utilization*

1122 We attempted to link the stream bed particle size data with fish size data in order to estimate the
1123 % spawnable area for the largest (Chinook) and smallest (pink) salmon that inhabit the Elwha
1124 River. We utilized several sources of data for this analysis including stream bed particle size and
1125 the body size of female Chinook and pink salmon (Wooster et al. 2009) (Figure 20). In order to
1126 do so we needed to make some basic assumptions regarding spawnable area for salmonids. First,

1127 we assume that a salmon spawning nest is limited by a maximum moveable stream bed particle
1128 size, the size of the female salmon, and flow conditions. Second, we assume that salmon
1129 spawning nests will decrease with an increase in the amount of “immovable” particles. Third,
1130 while we know salmon will utilize many different habitats for spawning, we assumed that the
1131 majority of spawning would occur where the tail out of a pool transitions into riffle areas (Quinn
1132 2005).

1133

1134 Lower Elwha Tribe has collected spatially specific spawning data since 2005 for the entire river
1135 below the lowermost dam (Aldwell dam), enabling us to compare existing spawnable area data
1136 to predicted spawnable area by examining Chinook redd locations over time. Thus we were able
1137 to identify the proportion of Chinook that spawn in the riffle crest areas relative to other areas in
1138 the Lower Elwha. We used tribal harvest data to estimate the average and standard deviation
1139 body mass of female Chinook. We assumed that female size in past years will be representative
1140 of female size in future years. To determine the fraction that is immobile we used the following
1141 equation:

1142

$$1143 \text{ Fraction immobile} = a + b * \left(\frac{g(\text{std dev})}{(D84^{1.5})} \right) + c * BMI$$

1144

1145 where;

$$1146 a = 0.94 \pm 0.05$$

1147

$$1148 b = -280 \pm 30.0$$

1149

$$1150 c = -0.078 \pm -0.07$$

1151

1152 $g(\text{std dev}) = \text{geometric standard deviation in mm}$

1153

1154 $D84 = \text{the 84\% of the stream bed particle size in each location}$

1155

1156 $BMI = \text{average body mass index size of}$

1157 $\text{Chinook} \left(5.41 \pm 0.06 \left(\frac{g}{mm} \right) \right) \text{ or pink salmon} \left(1.72 \pm 0.01 \left(\frac{g}{mm} \right) \right)$

1158

1159 To calculate the percent spawnable area identified a maximum percent spawnable area based on
1160 the percent immobile fraction (Figure x11).

1161

1162

1163 Results

1164 We sampled 24 locations in the Lower Elwha and 17 locations in the Middle Elwha (Figure 21).

1165 These sites were distributed throughout the main stem Elwha and included both pools and riffle

1166 crests (Figure 21). We found a decreasing trend in stream particle size from the Middle Elwha to

1167 the Lower Elwha (Figure 22a.). The Lower Elwha had a much steeper decrease in particle size

1168 from the dam to the mouth of the river, while the Middle Elwha trend was not as steep even
1169 though the distance was similar (6.62 kilometers v. 6.84 kilometers) (Figure 22b, and c.). Particle
1170 size distribution between the Middle Elwha and the Lower Elwha were similar (Table 11) with
1171 the Middle Elwha having a slightly larger overall average, but the difference was not significant
1172 (p -value = 0.321). Stream bed particle size was also similar on the up and downstream side of
1173 each riffle crest between the Lower and Middle Elwha (p -value=0.329 and p -value=0.421
1174 respectively). Examination of each individual site revealed that the upstream and downstream
1175 side of each of the riffle crest was similar in the majority of the locations in the Lower and
1176 Middle Elwha (Table 12). However over 40% of the riffle crests did have a significant difference
1177 between the upstream and downstream side (Table 12). In the majority of those cases the
1178 downstream side had a larger average particle size than the upstream side (13 of 17 riffle crests).
1179 Residual pool depth increased in the downstream direction (Figure 23). Mean residual pool depth
1180 in the Lower Elwha (2.39m \pm 0.28m) was significantly deeper than in the Middle Elwha (1.68m
1181 \pm 0.15m) (p = 0.019) (Figure 23). Importantly, pool depth did not vary as much between years as
1182 it did spatially (Figure 24). Differences between years (2.89 m, \pm 0.48m in 2009 v. 2.75m
1183 \pm 0.47m in 2000) were not significant (p = 0.156) in the Lower Elwha (Figure 24).

1184
1185 As expected, the proportion of immobile particles varied as a function of location and salmon
1186 species (Figure 25). There was a consistently higher trend of predicted immobile particles for
1187 pink relative to Chinook salmon due to their smaller average size. The immobile fraction for
1188 Chinook salmon ranged from 0% to a maximum of 50%, while the range for pink salmon was
1189 0% to 75%, with the majority of sites being greater than 50% immobile for pink salmon (Figure
1190 25). In each case there was a considerably smaller percentage of immobile particles in the lowest
1191 2km of the Elwha (Figure 25).

1192
1193 The percent fraction spawnable followed a similar pattern (Figure 26). The percent spawnable
1194 for Chinook salmon ranged consistently between 10% and 50%. The majority of riffle crest
1195 locations in the Lower Elwha had a predicted spawnable are between 25% and 50%, and the
1196 majority in the Middle Elwha ranged between 10% and 40% (Figure 26). The majority (48 of
1197 86) of predicted percent spawnable areas for pink salmon in the riffle crests were estimated to be
1198 0% while a much smaller proportion of the sites (12 out of 86) were estimate to be 0%
1199 spawnable for Chinook salmon (Figure 26).

1201 Discussion

1202 *Recommendations of protocol and pre-dam conclusions*

1203 Streambed particle size and residual habitat depth are key components of spawning habitat
1204 quality to measure when a known influx of sediment will occur with dam removal. These two
1205 variables should be continued to be measures systematically through the Elwha, above and below
1206 the dams, in order to gain an understanding of baseline condition. Additionally these twp metrics
1207 should be measured immediately post-dam removal and then periodically as a function of large
1208 scale distriburbance events including the dam removal and large flow events. Measurements

1209 should occur prior to spawning season in order to predict the location and density of spawning by
1210 salmonids.

1211

1212 In the Elwha River we found that streambed particle size decreases in a downstream direction
1213 below each of the dams, and decreases considerably in the lower 2km of the river before entering
1214 the Strait of Juan de Fuca. The decreasing trend in particle size is greater in the Lower Elwha
1215 than the Middle Elwha. Within site variation is typically not significant, but there are portions of
1216 the riffle crest sites that exhibit a significant differences between the upper and lower transects of
1217 the riffle crest. The sites that exhibit a significant difference between the upstream and
1218 downstream portion of riffle crests are evenly distributed between the Lower and Middle Elwha.
1219 In general, residual pool depth increases in the downstream direction, however, residual pool
1220 depth does decrease in the lowest portion of the Lower Elwha. Residual pool depths are
1221 significantly different between the Middle and Lower Elwha, but the difference between years
1222 for the same pools surveyed is not significantly different. Predicted percent spawnable area
1223 varies by species but is greatest in the Lower Elwha, particularly in the lowest portion of the
1224 Elwha below Rkm 2.5. The probability of a site having spawnable area is greater for Chinook
1225 salmon than pink salmon, but at a given site there is typically a larger predicted percent
1226 spawnable area for pink salmon relative to Chinook salmon.

1227

1228

1229

1230 **General recommendations - What methods might be most appropriate for the Elwha?**

1231 Maintain and expand the current adult salmon enumeration activities including redd surveys,
1232 SONAR, and the fish weir. Expansion includes other species besides Chinook salmon and
1233 steelhead. Expansion to other species and methods is particularly important because of the
1234 limited visibility that will occur with dam removal. We recommend augmenting visual surveys
1235 with alternate enumeration methods such as the weir and imaging SONAR. While neither of
1236 these methods has been tested across seasons in the Elwha, they have been effectively used at
1237 other sites, and could be used in other dam removals as well. In addition the weir and sonar have
1238 the potential to be complimentary. Further identify salmon populations in other watersheds that
1239 track well with salmonids in the Elwha to help identify trends associated with the dam removal
1240 v. other factors such as ocean conditions. Adult enumeration needs to be ongoing and annual pre
1241 and post dam removal for at least 2 to 3 generations of salmon, which is a function of their life
1242 history.

1243 Developing estimates of “standing crop” juvenile salmon populations in different habitats prior
1244 to dam removal is important to aid in understand how colonization occurs in the Elwha and at
1245 other dam removal locations. Multiple methods such as snorkeling, electroshocking, and seining
1246 can be used to meet this objective. While each method for juvenile enumeration is capable of
1247 effectively estimating presence/absence and species diversity across a wide range of conditions,
1248 snorkeling identifies the largest number of fish and the greatest diversity of fish size. Multi-pass
1249 electrofishing and seining are most appropriate for surveying short sections of small streams with
1250 shallow, minimally complex habitat and a diverse population assemblage. Seining is most
1251 effective of all methods when visibility is poor. We recommend that such efforts be made at least
1252 once prior to dam removal and at least three times over a period of a decade to get a better
1253 understanding of relative abundance and distribution over time.

1254

1255 More importantly we recommend that a larger effort be taken to maintain and improve the Elwha
1256 screw trap for outmigrating salmonid smolts because it is a better indicator of overall juvenile
1257 productivity from the watershed. Dam removal will likely affect the trap operation. During the
1258 period of high turbidity immediately after the dam removal, the trap efficiency will likely
1259 change. Also, the input of large amounts of sediment and wood may substantially change the
1260 current trap site requiring the location of another site. Estimates of smolt production could be
1261 improved by modifying the trap or site, or moving the trap in order to increase trap efficiency. In
1262 addition we recommend increasing and modifying the releases for estimating efficiency by using
1263 additional species beyond chum and conducting night efficiency estimates. Smolt outmigration
1264 monitoring should be annual pre and post dam removal for at least 2 to 3 generations of salmon.

1265

1266

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1533

1534 **Tables and Figures**

1535

1536 **Adult enumeration - The effectiveness and application of different adult salmonid**
1537 **enumeration methods**

1538 Table 1. A summary of the available data for Elwha river salmon and steelhead populations.
1539

Species	Number of Years	Methods	Population range	Principal group responsible for data collection	Data quality
Chinook	1976 - Current 2008 - Current	Redds/Adults SONAR		WDFW/LEKT NOAA/LEKT	moderate poor- moderate
Coho	-	-	-	-	-
Chum	1993,1994	Live counts & Mark recapture	150-250	USFWS	unknown
Pink	2009	Adult snorkel	100 +	NOAA	unknown
Steelhead (winter)	2005 - Current	Redds		LEKT	low
Steelhead (summer)	-	-		-	-

1540

1541

1542 Table 2. Correlation of a.Chinook salmon, b. coho salmon, and c. winter steelhead from 1975 to
1543 2008 for the Elwha, Quillayute, Queets, and Hoh rivers on the Olympic Peninsula, Washington
1544 State.

1545 a.

	Elwha	Quillayute	Queets	Hoh
Elwha	1.00	0.75	0.71	0.58
Quillayute	0.75	1.00	0.76	0.70
Queets	0.71	0.76	1.00	0.93
Hoh	0.58	0.70	0.93	1.00

1546

1547 b.

	Quillayute	Queets	Hoh
Quillayute	1.00	0.81	0.82
Queets	0.81	1.00	0.79
Hoh	0.82	0.79	1.00

1548

1549 c.

	Quillayute	Queets	Hoh
Quillayute	1.00	-0.26	0.23
Queets	-0.26	1.00	0.35
Hoh	0.23	0.35	1.00

1550

1551

1552 Table 3. A comparison of the different methods for estimating adult escapement for salmon in
1553 the Elwha River. E = excellent, G = good, F = fair, and P = poor for a given species and method
1554 based upon assessment of the method and typical Elwha River water clarity at a given season.

Method	Chinook	Coho	Chum	Pink	Steelhead	Steelhead (S)	Pros	Cons
Visual surveys	G	P	P	G	F	P	Well understood. Relatively simple to implement. Spatial information.	Need good visibility. Effort scales with size of river.
SONAR	F	?	?	F?	?	F?	Can work in turbid water. Potential for year round operation.	Difficulty differentiating species. Long processing time.
Weir	E	P	P	E	P	G	Very accurate. Can handle fish for measurements, tagging and exclusion.	Cannot operate during much of fall, winter, and spring due to high flows.

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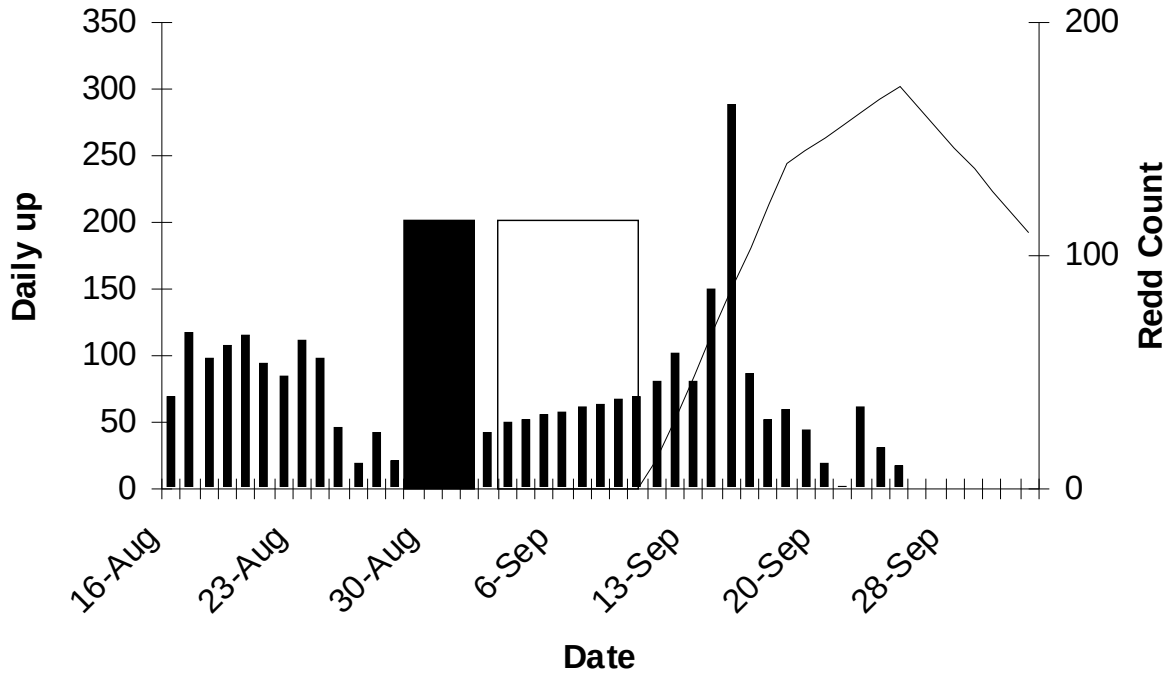
1556

1557 Table 4. Estimated annual rates of increase based on the exponential growth phase of six
1558 colonizing populations.

Species	Location	Population growth rate (r)
Pink salmon	Fraser River (Above Hell's Gate), British Columbia, Canada	1.18
Pink salmon	Glacier Bay, Southeast Alaska	2.01
Pink salmon	South Fork Skykomish, Puget Sound, Washington State	1.18
Coho salmon	Cedar River, Puget Sound, Washington State	2.08
Chinook salmon	Cedar River, Puget Sound, Washington State	1.95
Chinook salmon	South Fork Skykomish, Puget Sound, Washington State	1.28

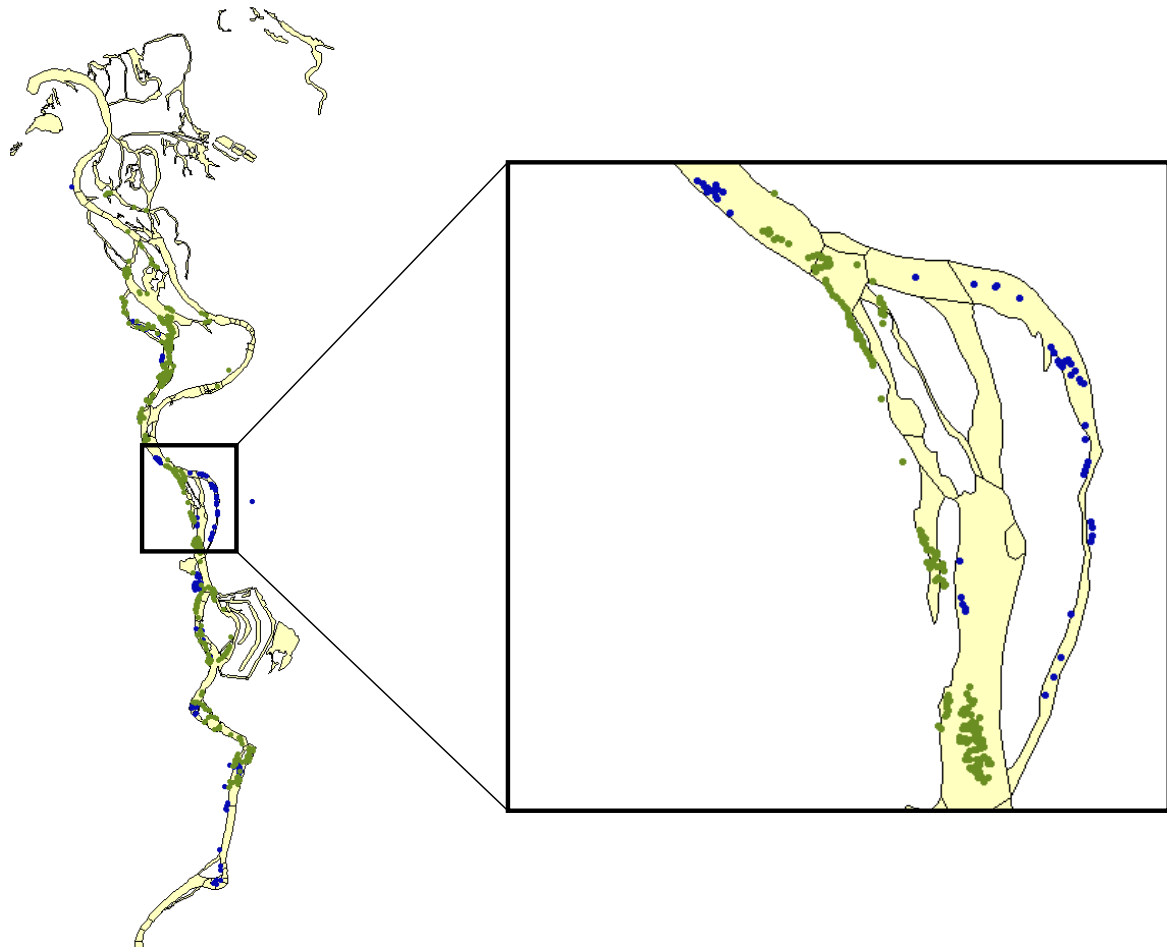
1559 Figure 1. Daily upstream counts of adult Chinook salmon in the Elwha River as determined by
1560 SONAR, and redd counts from WDFW surveys. Red boxes indicate SONAR data that was
1561 interpolated from nearby data. Solid black bars indicate daily upstream movement past the
1562 SONAR. Continuous solid black line indicates cumulative Chinook salmon redd count.

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1566 Figure 2. a. Chinook salmon redd locations in the lower Elwha River for 2004 (blue)
1567 (green).



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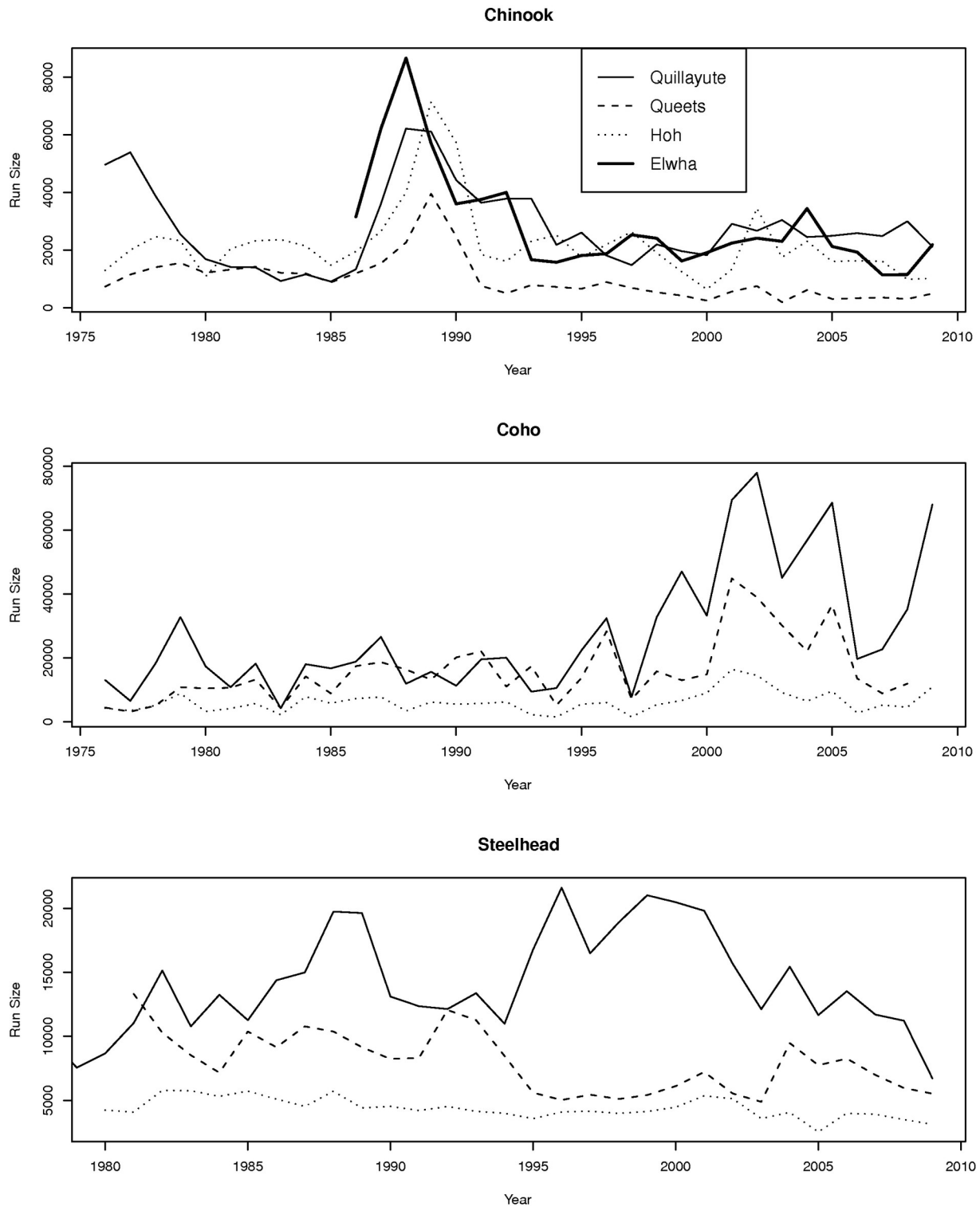
1570 Figure 3. Locations of winter steelhead redds in the Elwha River in 2010. White dots indicate
1571 4/1/2010 survey, yellow dots indicate 4/14/2010 survey, Green dots indicate 4/30/2010 survey,
1572 and blue dots indicate 5/10/2010 survey.

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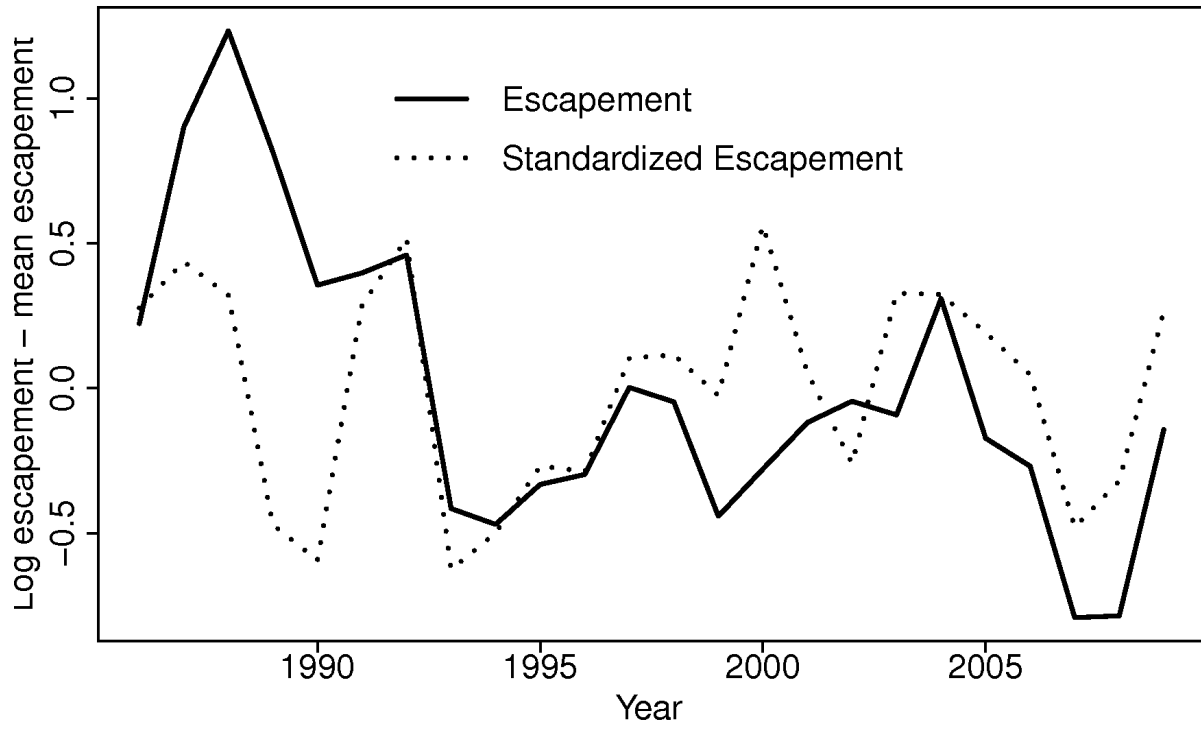
1575 Figure 4. A comparison of adult salmon run size trends for four rivers on the Olympic Peninsula,
1576 Washington State for Chinook salmon, coho salmon, and steelhead 1975 to 2008. It is important
1577 to note that there are no estimates of coho salmon and steelhead for the Elwha River.



1578

1579 Figure 5. Comparison of the standardized and unstandardized Chinook escapement time series
 1580 for the Elwha River. Values are logged and centered at zero by subtracting the mean.

1581



1582

1583

1584 Figure 6. Photo of resistance board weir in the Williamson River, OR, a tributary of the Klamath
1585 River in Oregon and Washington state. Flow is going from right to left, trap boxes are in the
1586 center right foreground and center background of photo.

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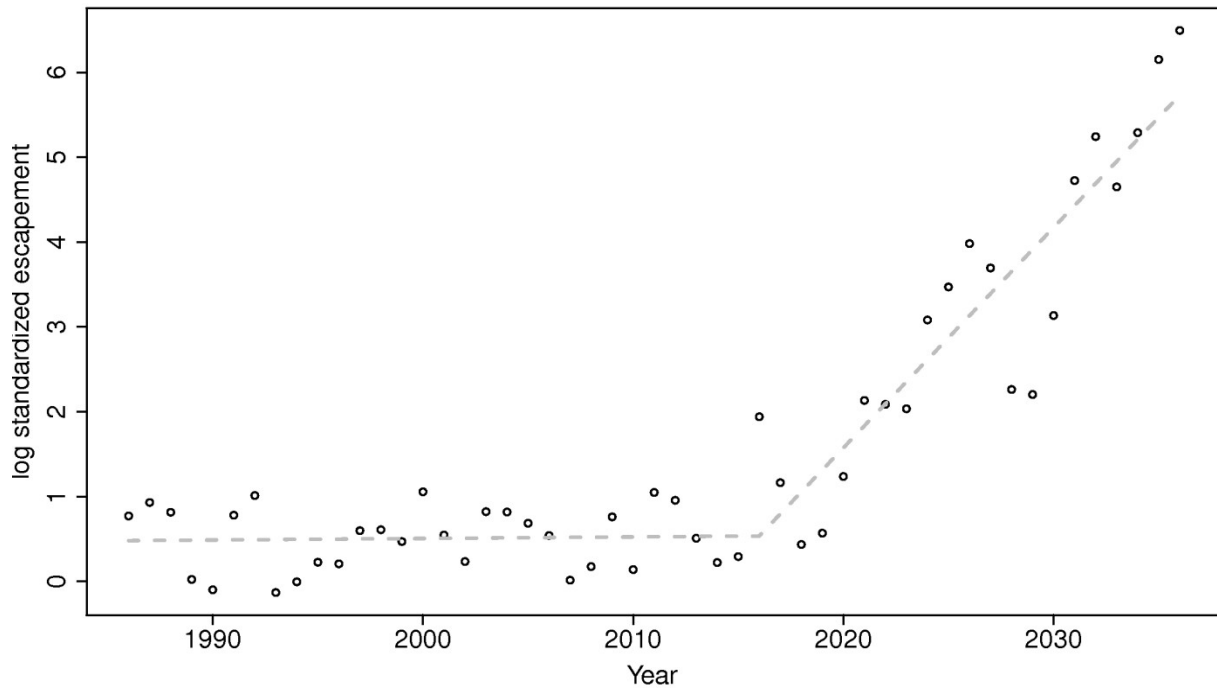
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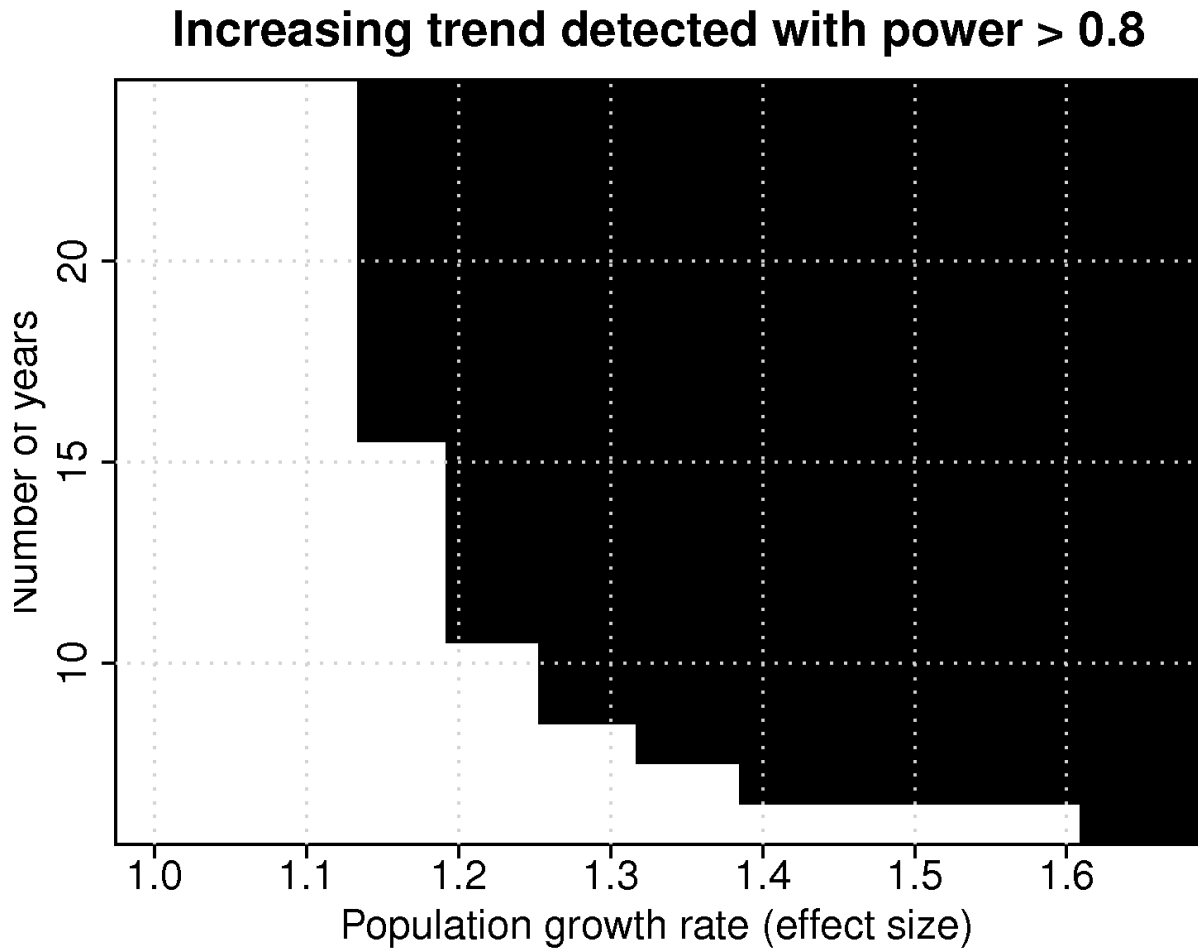
1598 Figure 7. An example of a simulated standardized time series before and after dam removal for
1599 Chinook salmon the Elwha River. The increasing linear trend on the log scale translates to an
1600 exponential trend in the standard scale.



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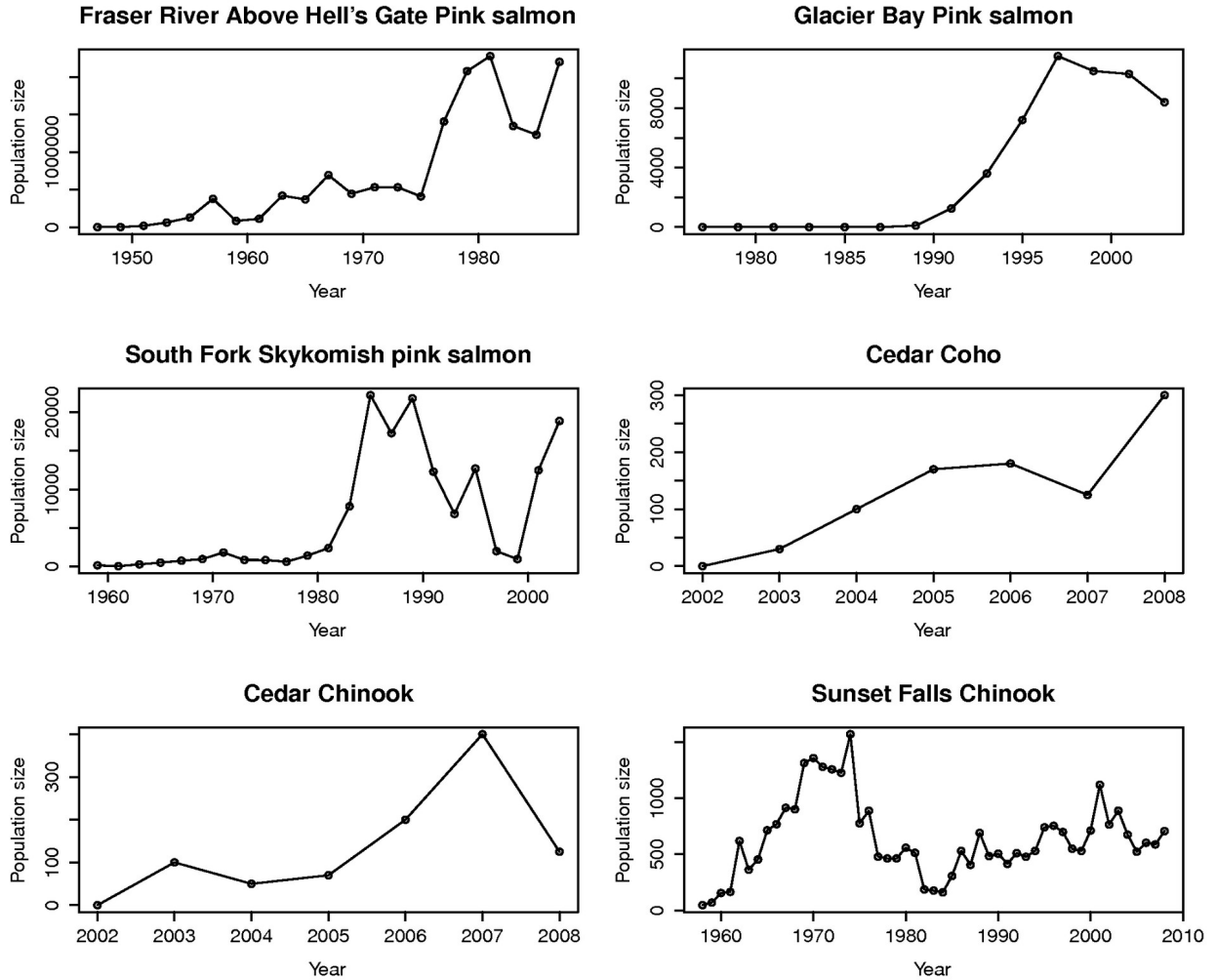
1603 Figure 8. A power analysis to determine the number of years needed to monitor adult Chinook
1604 salmon in the Elwha River to determine a “significant” increase in population size due to dam
1605 removal. The black region represents the area where the power to detect a change in population
1606 size is greater than 0.8.



1607

1608

1609 Figure 9. Pink, coho, and Chinook salmon population trajectories for six colonization events
1610 across the Western Pacific Rim 1947 to 2010.



1611

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1614 **Juvenile enumeration - The effectiveness and application of different juvenile salmonid enumeration methods**

1615 Table 5. Description of the relative tradeoffs between the different methods commonly used to enumerate juvenile salmonids in
 1616 streams, including the conditions under which each method has low and high efficiency, the important factors to consider regarding
 1617 fish injury, spatial coverage and underwater visibility, the length of stream that can be covered on a daily basis, and the number of
 1618 people needed to conduct each method.

1619

Method	Low efficiency	High efficiency	Important factors	Daily coverage	Crew size
Electrofishing	Large and deep streams with complex cover, smaller fish	Small and shallow streams with minimal cover, medium to larger fish	Can be injurious to fish and is not influenced by visibility	100's of meters	3 - 4
Snorkeling	Shallow streams with complex cover and sometimes smaller fish and juvenile trout, charr	Streams and rivers with minimal to moderate cover and juvenile salmon and sometimes trout, charr	Non-injurious to fish and applicable to widest range of stream sizes and depths	1 - 2 kilometers	2 - 3
Seining	Large and deep streams with complex cover, smallest-sized fish and benthic species	Small and shallow streams with minimal cover, larger fish and non-benthic species	Non-injurious to fish and not influenced by visibility	100's of meters	3 - 5

1620

1621 Table 6. Description of habitat units sampled during May of 2010.

Unit	Length (m)	Width (m)	Maximum depth (m)	Tail crest depth (m)	Instream Cover (m ²)	Cutbank (m)	Cutbank depth (m)	Main cover features	Dominant Substrate	Subdominant Substrate
1	19.2	11.3	1.2	0.3	20	5	0.1	Depth, wood Undercut banks	Boulder	Cobble
2	52	10.5	0.8	0.2	3	13	0.3	Velocity Stream bottom	Boulder	Cobble
3	8.1	2.4	0.3	0.1	1	1	0.1	Depth	Cobble	Gravel
4	22.4	10.5	0.3	0.1	0	0	0	Depth	Cobble	Gravel
5	27	7	1.1	0.2	1	8	0.2	Depth	Gravel	Pebble
6	7	5.2	1.3	0.1	0	3	0.2	Depth	Cobble	Gravel

1622

1623 Table 7. Time and sample ability of each unit sample in the Elwha River

Unit	Snorkel time (min)	Shock time (min)	Seine time (min)	Snorkelability	Shockability	Seinability
1	16	48	40	5	2	4
2	15	37	53	5	3	3
3	4	10	5	5	5	4
4	4	15	12	5	5	5
5	8	15	23	5	3	3
6	4	20	20	5	1	1

1624 Figure 10. Conceptual graph of “sample ability index.”

1625

Eletroshocking

1626

1627

1

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5

1628 ■

1629 Consistently deep
1630 Roughness everywhere
Short or long

Sporatically deep
Roughness but in specified places
Relatively long

Consistently shallow
No obstructions such as wood
Relatively short

1631

1632

Seining

1633

1634

1

2

3

4

5

1635 ■

1636 Large variation in depth
Roughness everywhere
Short or long

Deep but consistent
Roughness but in specified places
Relatively long

Consistently shallow
No obstructions such as wood
Relatively short

1637

1638

1639

Snorkeling

1640

1641

1642

1

2

3

4

5

1643 ■

1644 Very shallow,
Lots of wood everywhere,

Moderately deep
Some cover such as wood
Longer unit

Deep
Wood specified areas to view
Long unit

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1652 Table 8. Total catch by species, age class and origin (hat=hatchery).
 1653

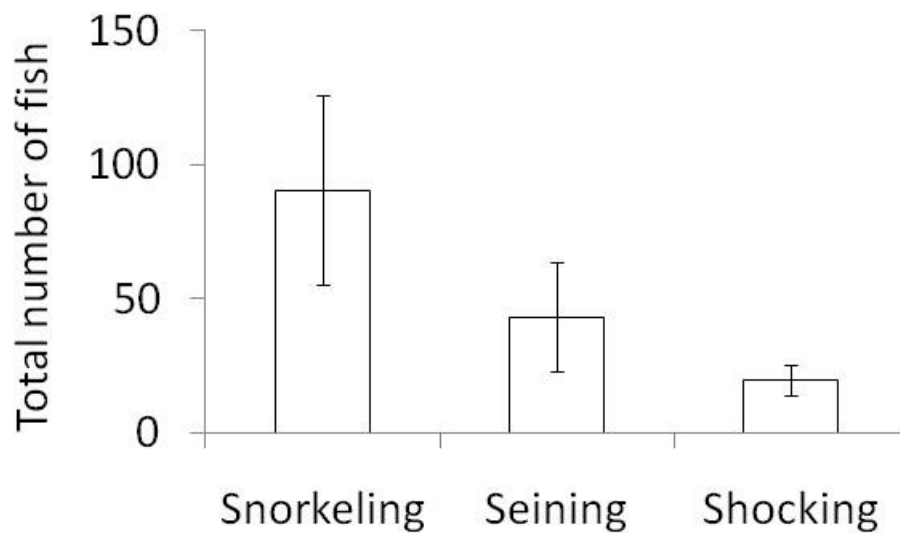
	2005	2006	2007	2008	2009
bull trout	1	1	0	0	0
Chinook 0+	5011	3376	266	641	1035
Chinook 1+	0	51	51	1	36
Chinook hatchery	4997	3898	0	0	NA
chum	5255	8698	1313	2208	2813
coho 0+	2696	4527	129	105	1276
coho 1+	1098	310	68	17	21
coho hatchery	204	227	11	8	6
cottids	141	191	14	629	730
cutthroat	4	0	0	0	NA
eulachon	20	20	1	1	3
lamprey	24	34	4	17	32
pink	0	690	0	288	272
starry flounder	5	0	0	0	NA
steelhead	0	172	17	5	2
steelhead hatchery	283	345	38	29	0
stickleback	8	38	6	1	0
trout 0+	53	17	2	3	2
trout 1+	149	20	3	6	0
trout 2+	96	7	1	9	1

1654

1655 Table 9. Estimates and 95% confidence intervals for the Chinook 0+, pink and chum out
 1656 migrants for the Elwha River.
 1657

Year	Chinook 0+	pink	chum
2005	17,4019 (±165,924, 182,115)	0 (±0,0)	157,125 (±148,621, 165,629)
2006	119,357 (±115,914,122,800)	21,375 (±20,478, 22,271)	276719 (±271,777, 281,661)
2007	14,309 (±10,819, 17,798)	0 (±0,0)	58473 (±49,717, 67,229)
2008	18,603 (±16,678, 20,528)	7,052 (±5,992, 8,112)	46884 (±44,031, 49,736)
2009	13,812 (±12,923, 14,702)	4,129 (±3,630, 4,628)	45336 (±43,450, 47,222)

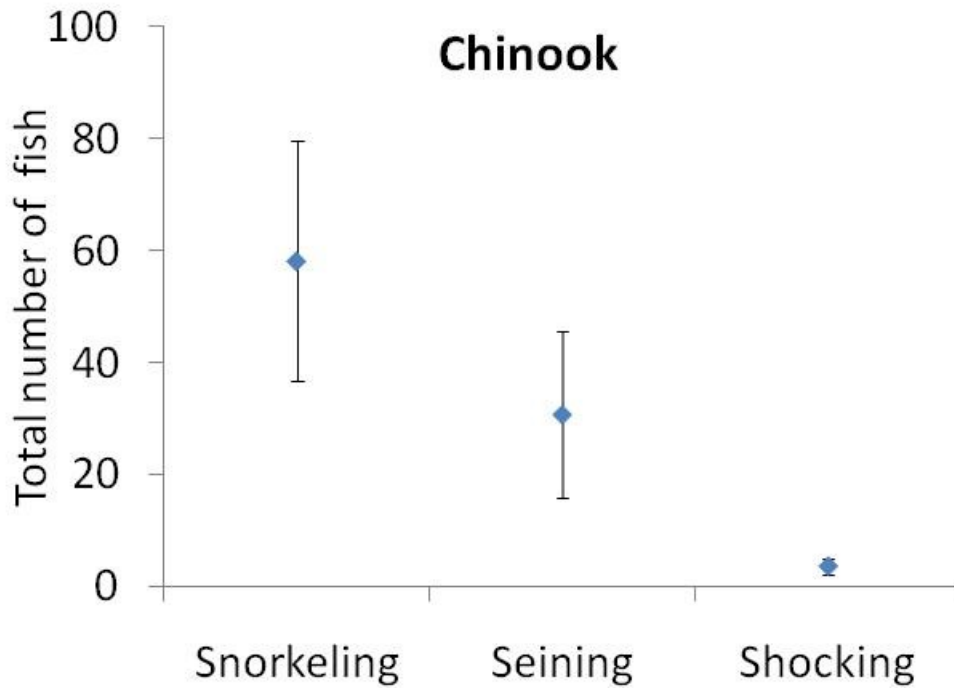
1658 Figure 11. Total number of identified by snorkeling or captured by electroshocking or seining
1659 from six units in one side-channel of the Lower Elwha River 2010. Clear boxes indicate average
1660 for each method, while solid bars with hash marks at upper and lower end indicate the standard
1661 error (S.E.) for each method.
1662
1663



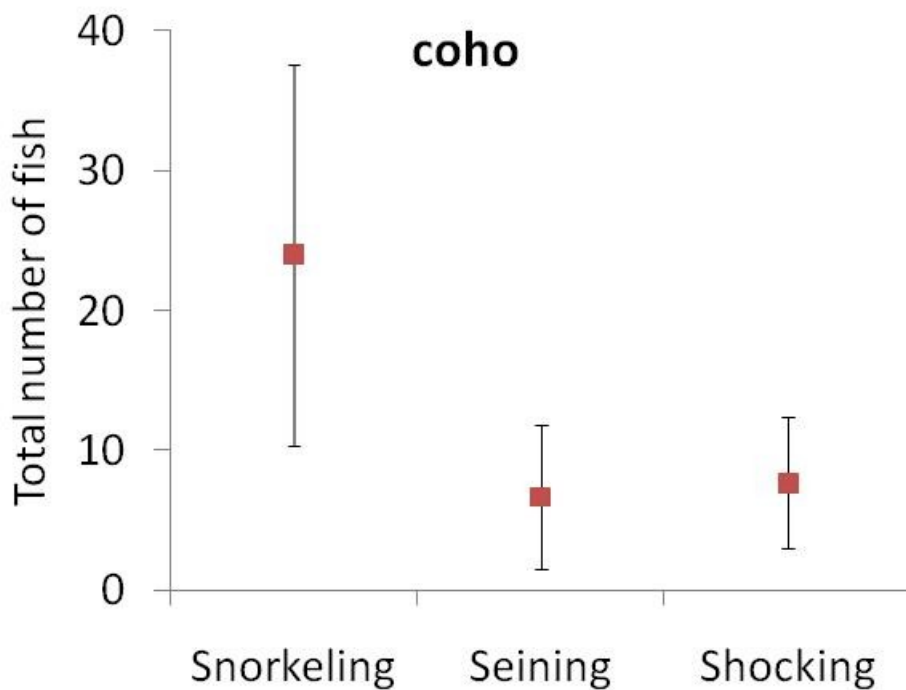
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1667 Figure 12. Total number of a. juvenile Chinook salmon, b. juvenile coho salmon, and c. juvenile
1668 rainbow trout/steelhead identified by snorkeling or captured by electroshocking or seining from
1669 six units in one side-channel of the Lower Elwha River 2010. Clear boxes indicate average for
1670 each method, while solid bars with hash marks at upper and lower end indicate the standard error
1671 (S.E.) for each method.

1672 a.
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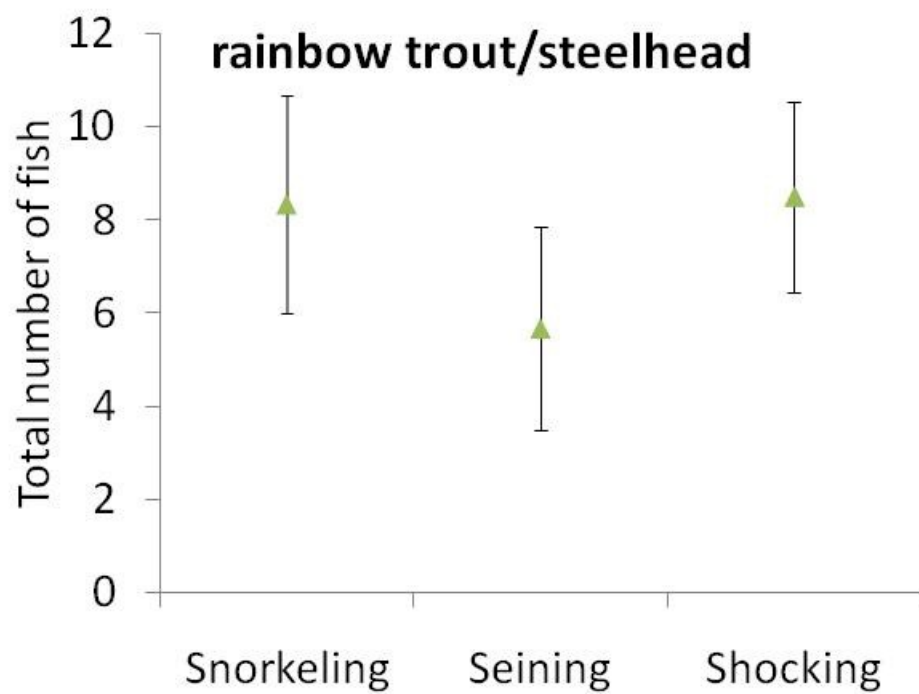


1674 b.
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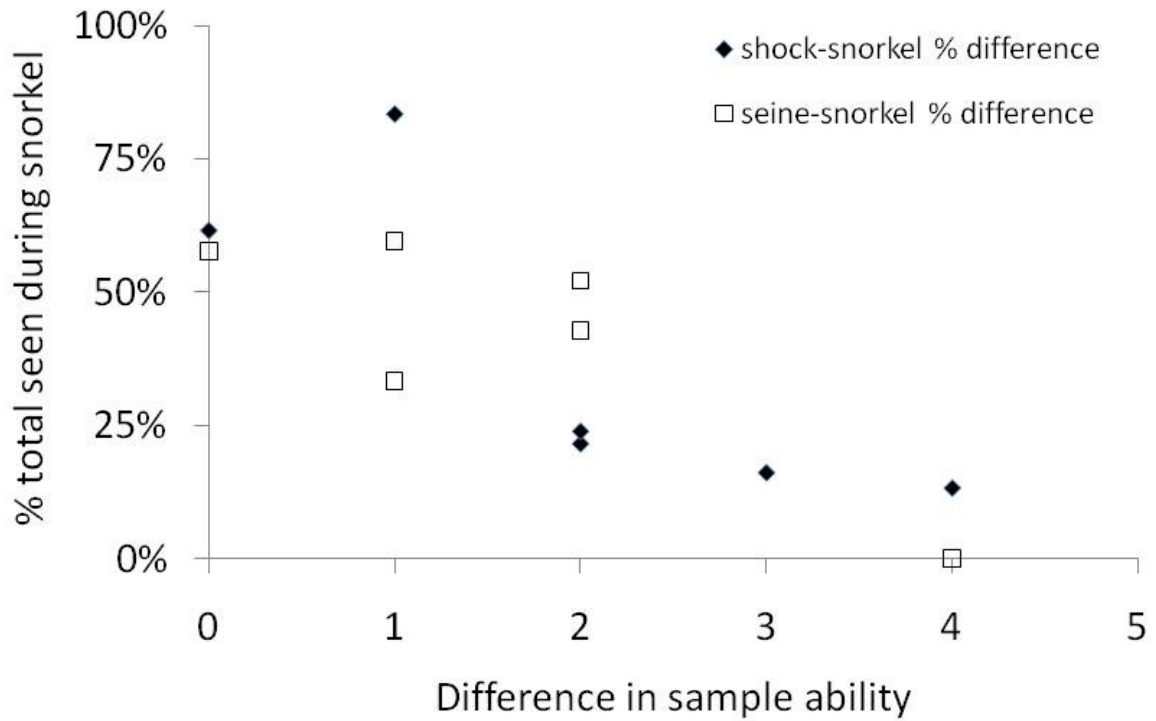
1677
1678 c.



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Figure 13. Difference in sample ability between snorkeling and the other methods (either electroshocking or seining) v. % see during snorkel v. the other methods. The greater the difference in sample ability the greater the degree of difficulty in using either electroshocking or seining relative to the snorkelability for a given area of stream.



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1694 Figure 14. Differences in the size class distribution of a. juvenile Chinook salmon, b. juvenile
1695 coho salmon, and c. juvenile rainbow trout/steelhead captured by electroshocking and seining
1696 from six units in one side-channel of the Lower Elwha River 2010.

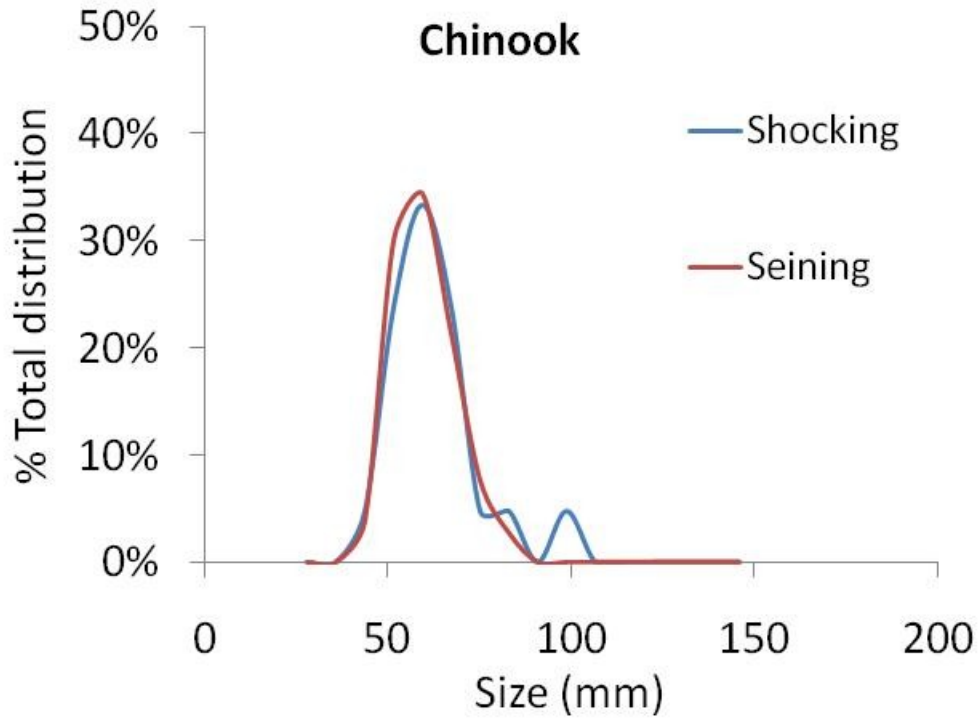
1697 a.

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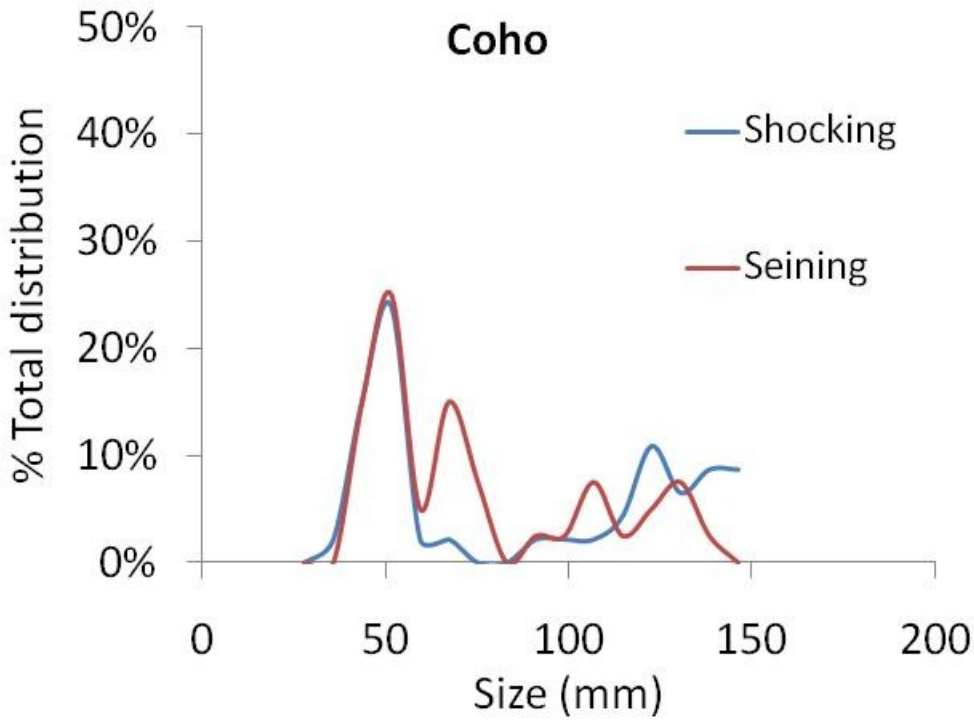
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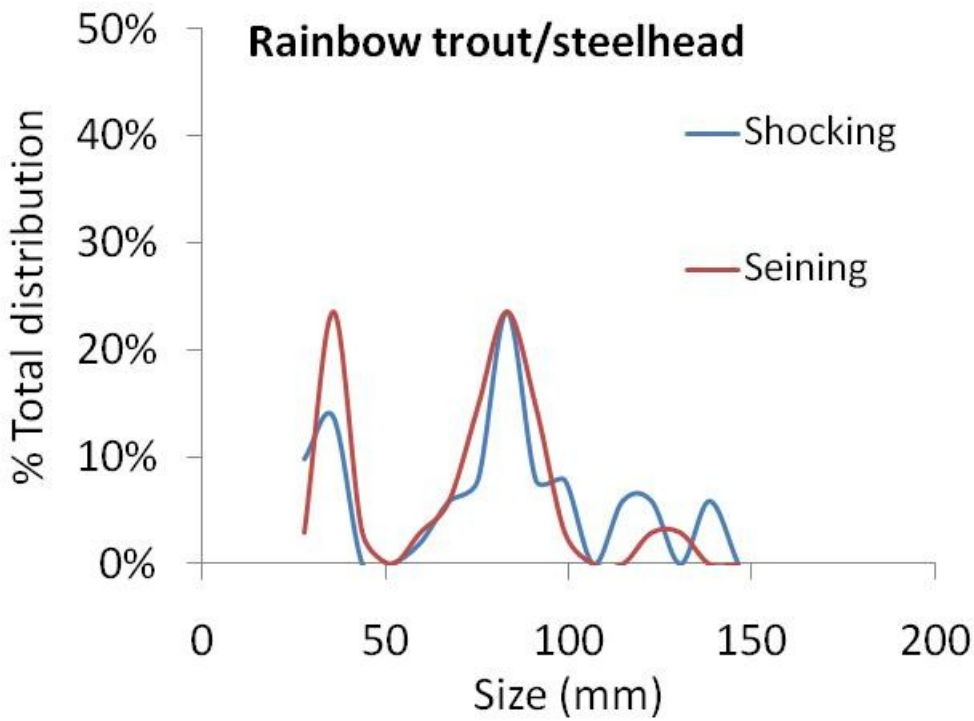
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1702
1703 b.

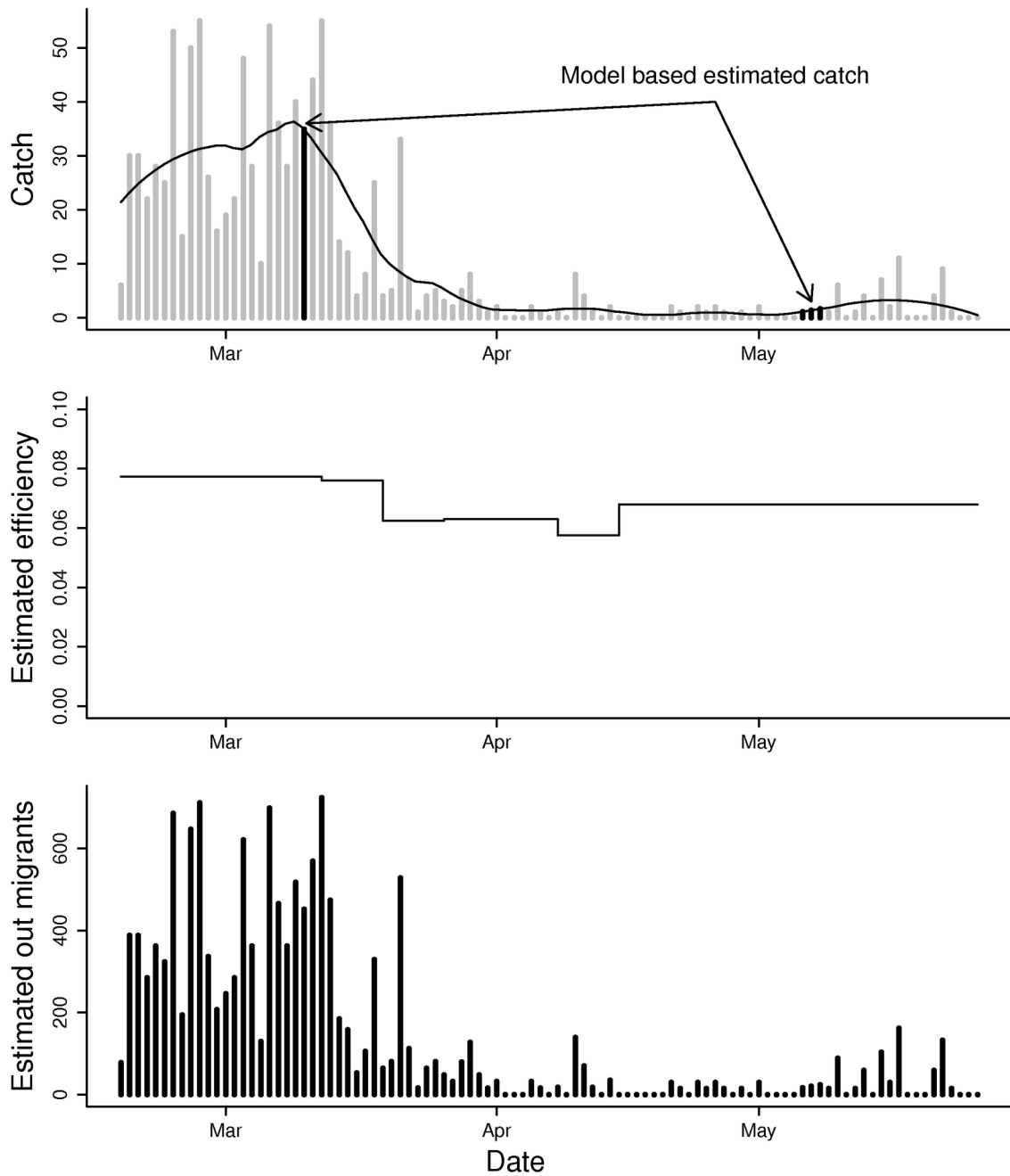


1704
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1706 c.
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1708

1709 Figure 15. Plots illustrating the process of estimating total Chinook 0+ out migrants for 2009.
1710 The top panel shows the catch data in gray, the loess model fit to the data (the line), and the
1711 interpolated values where catch data was missing (black bars). The middle panel shows
1712 efficiency over time, and the bottom panel is the final estimate of total out migrants.
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1714
1715



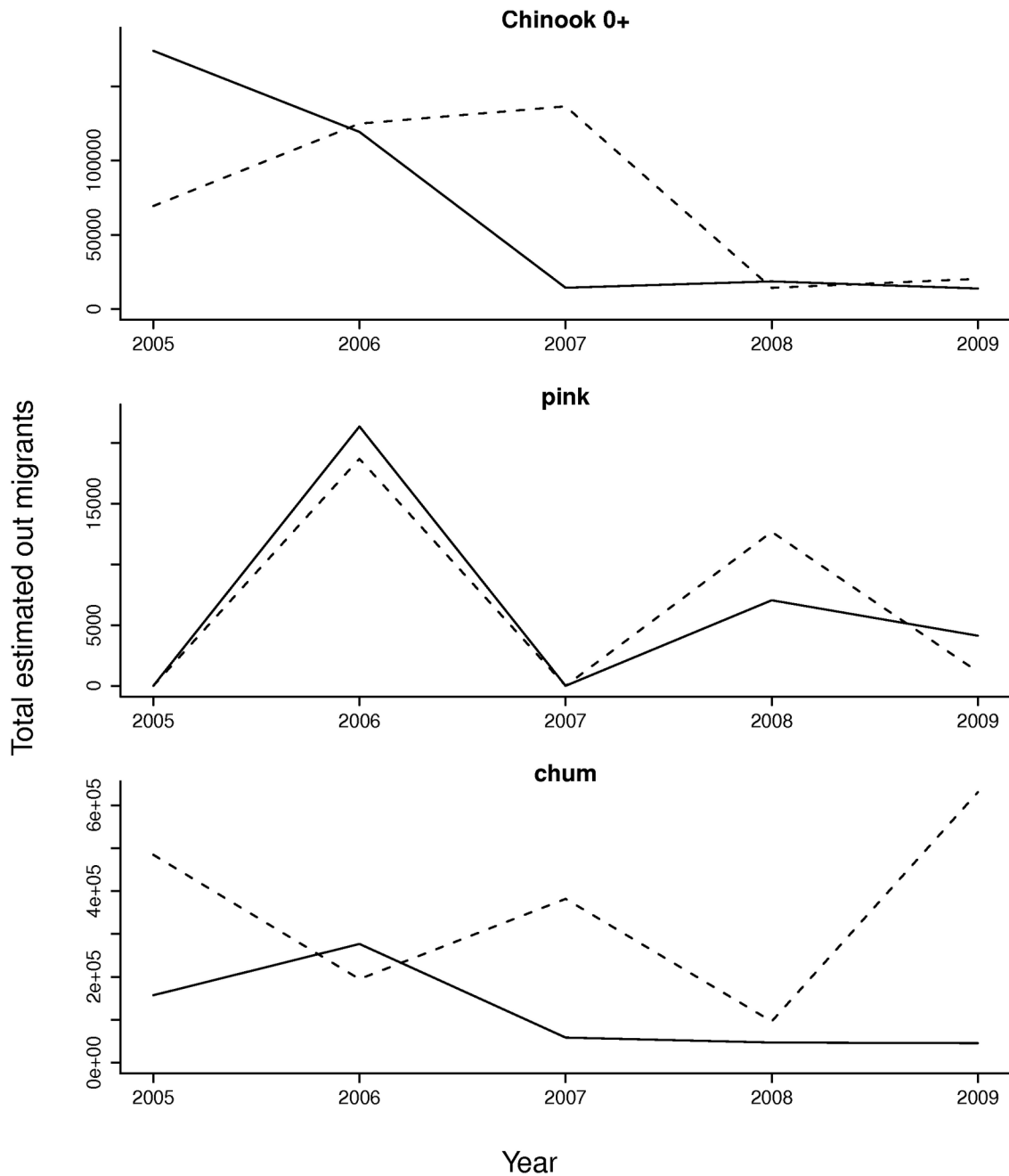
1716
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1719 Figure 16. Trends in total out migrants for Chinook 0+, pink and chum salmon. The solid line
1720 represents the Elwha estimates and the dashed line the Dungeness River estimates. For pink
1721 salmon the Dungeness estimates were multiplied by the mean of the Elwha series divided by the
1722 mean of the Dungeness series in order to place the values on a comparable scale (raw Dungeness
1723 values are much higher than the Elwha values).

1724

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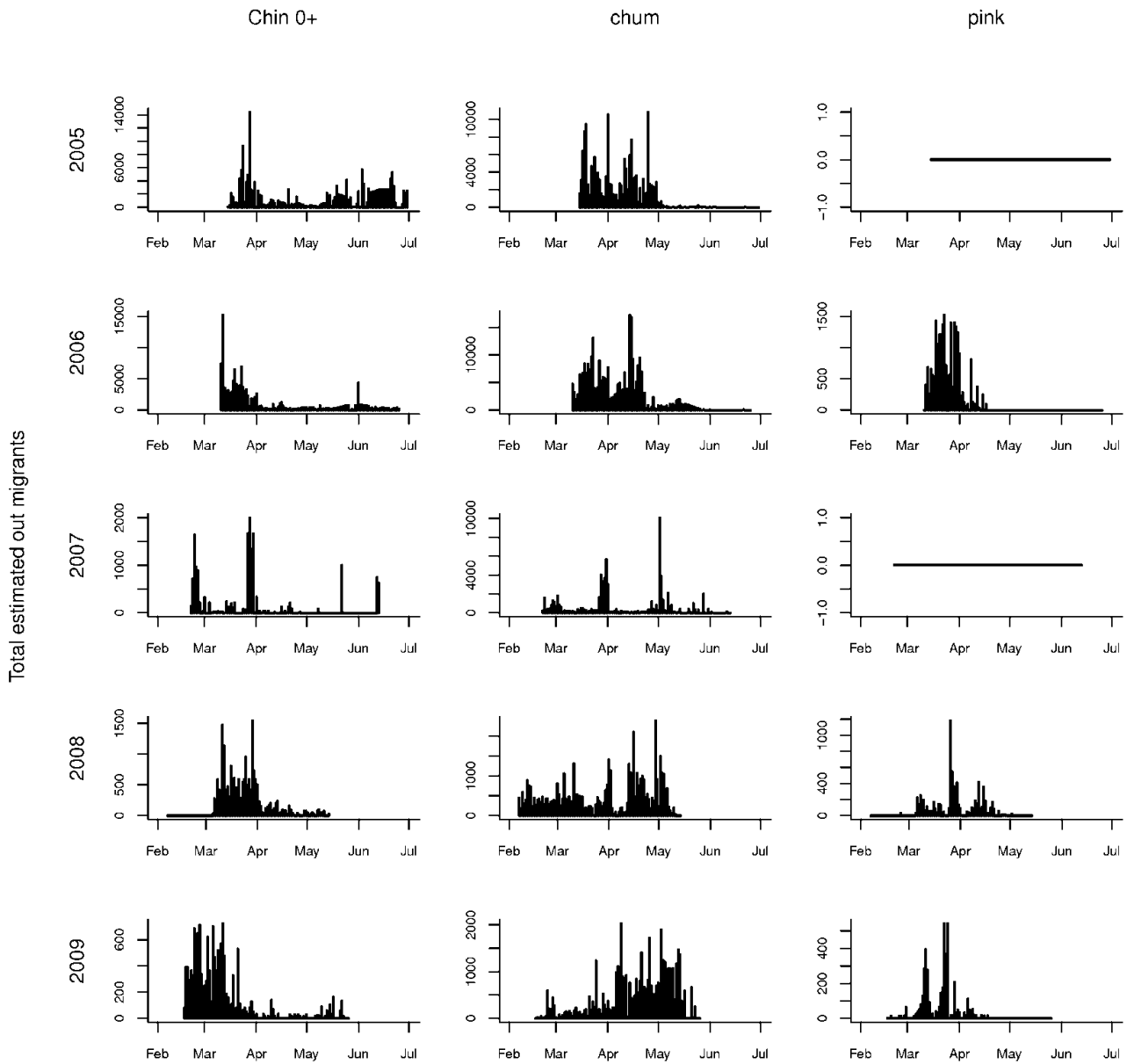


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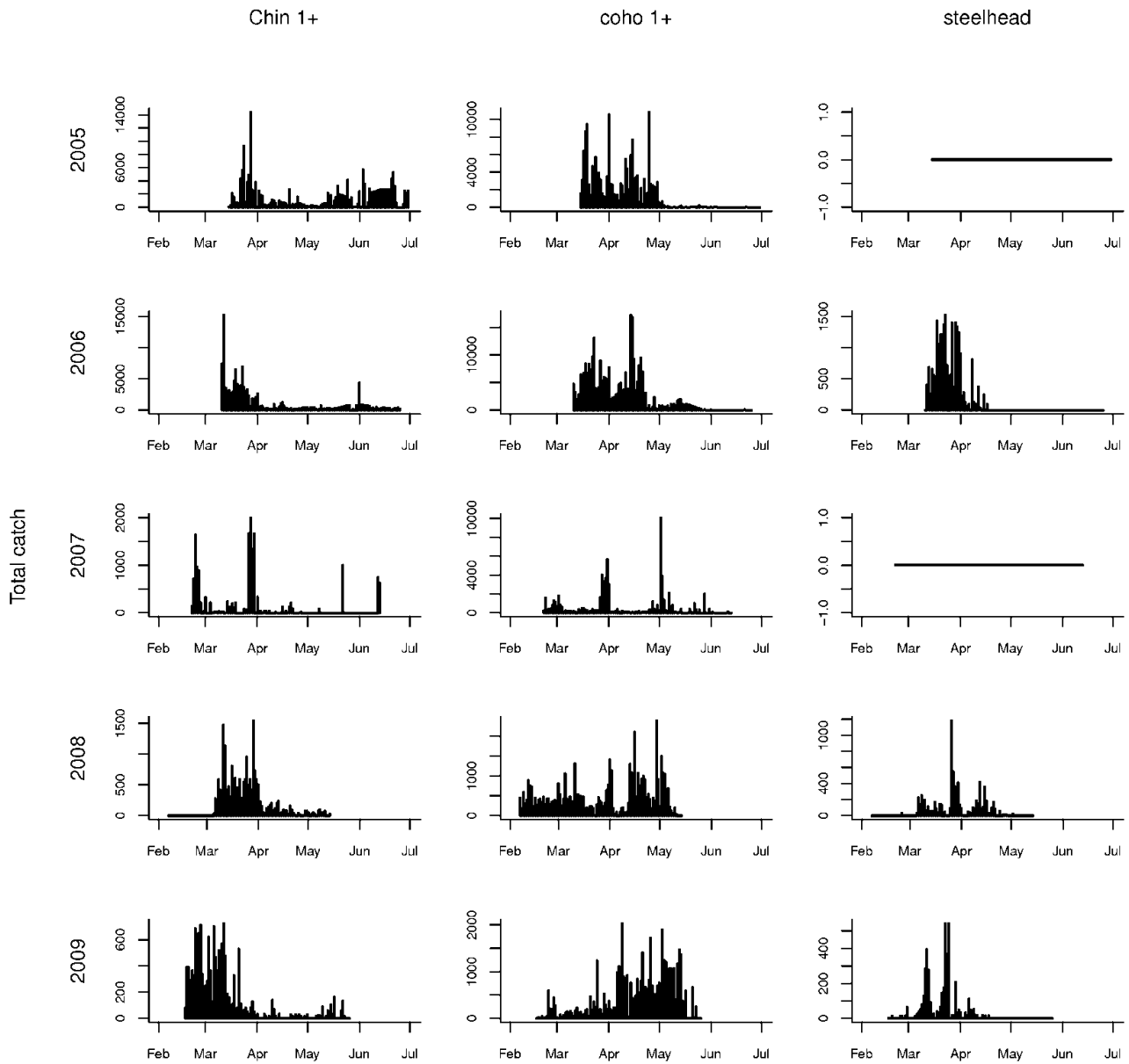
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Figure 17: Total estimated out migrants for 2005-2009, Chinook 0+, chum, and pink (the species for which efficiency estimates were deemed reliable).



1733 Figure 18. Total catch for 2005-2009, Chinook 1+, coho 1+, and steelhead (the species with
 1734 larger bodied smolts for which efficiency estimates were deemed unreliable).
 1735
 1736



1738 **Habitat surveys - How does spawning habitat quantity and quality vary by habitat type,**
1739 **spatial location, and pre and post dam removal?**

1740 Table 10. Data collect for habitat quality parameters – residual pool depth and particle size
1741 distribution.

Site
Longitude
Latitude
Reach location
River mile
River kilometer
Pool length
Pool width
Stream bankfull width
Pool maximum depth
Pool tail depth
Pool residual pool depth
Riffle area upstream
Riffle area downstream
Particle size for each rock measured
(200 per riffle, 100 on the upstream side and 100 on the downstream
side)

1742

1743

1744 Table 11. Distribution of particle size distribution between the middle and lower Elwha River.
1745 Standard error is in parentheses.

1746

Particle Size (mm)	Lower Elwha	Middle Elwha
D16	52 (± 4)	52 (± 4)
D50	114 (± 7)	136 (± 6)
D75	170 (± 9)	230 (± 8)
D84	202 (± 10)	275 (± 9)

1747

1748

1749

1750 Table 12. Average particle size distribution for each riffle crest sampled in the Lower and
1751 Middle Elwha River 2009. Bold indicates that p-value was less than 0.10.

Location	Upstream(mm)	Downstream (mm)	P – value
p2	110	103	0.373
p4	110	133	0.036
p8	83	92	0.150
p100	250	240	0.650
p101	247	451	0.157
p102	284	193	0.002
p103	283	426	0.472
p105	169	189	0.240
p107	142	139	0.792
p108	93	77	0.166
p109	141	142	0.942
p110	97	80	0.074
p111	116	127	0.270
p112	98	104	0.417
p113	102	118	0.100
p114	104	118	0.096
lerc6	51	53	0.892
lep7	66	92	0.003
lerc10	82	111	0.007
lep12	121	124	0.757
lep13	112	123	0.235
lep114	107	90	0.030
lep115	123	143	0.068
mep1	163	200	0.035
mep2	200	221	0.258
merc3	173	183	0.554
mep4	121	151	0.048
mep5	122	158	0.017
mep6	175	195	0.357
mep7	190	197	0.671
mep8	185	159	0.134
mep9	204	152	0.026
mep10	145	178	0.092
mep11	167	141	0.289
mep12	168	204	0.097
mep13	124	140	0.294
mep14	204	186	0.404
mep115	118	148	0.005
mep116	123	149	0.036

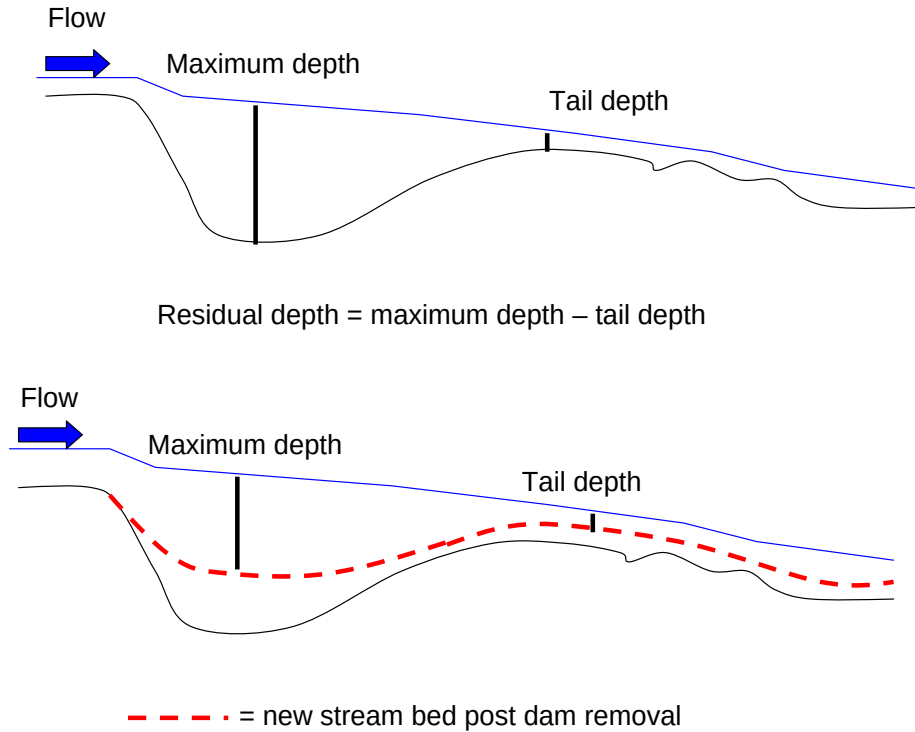
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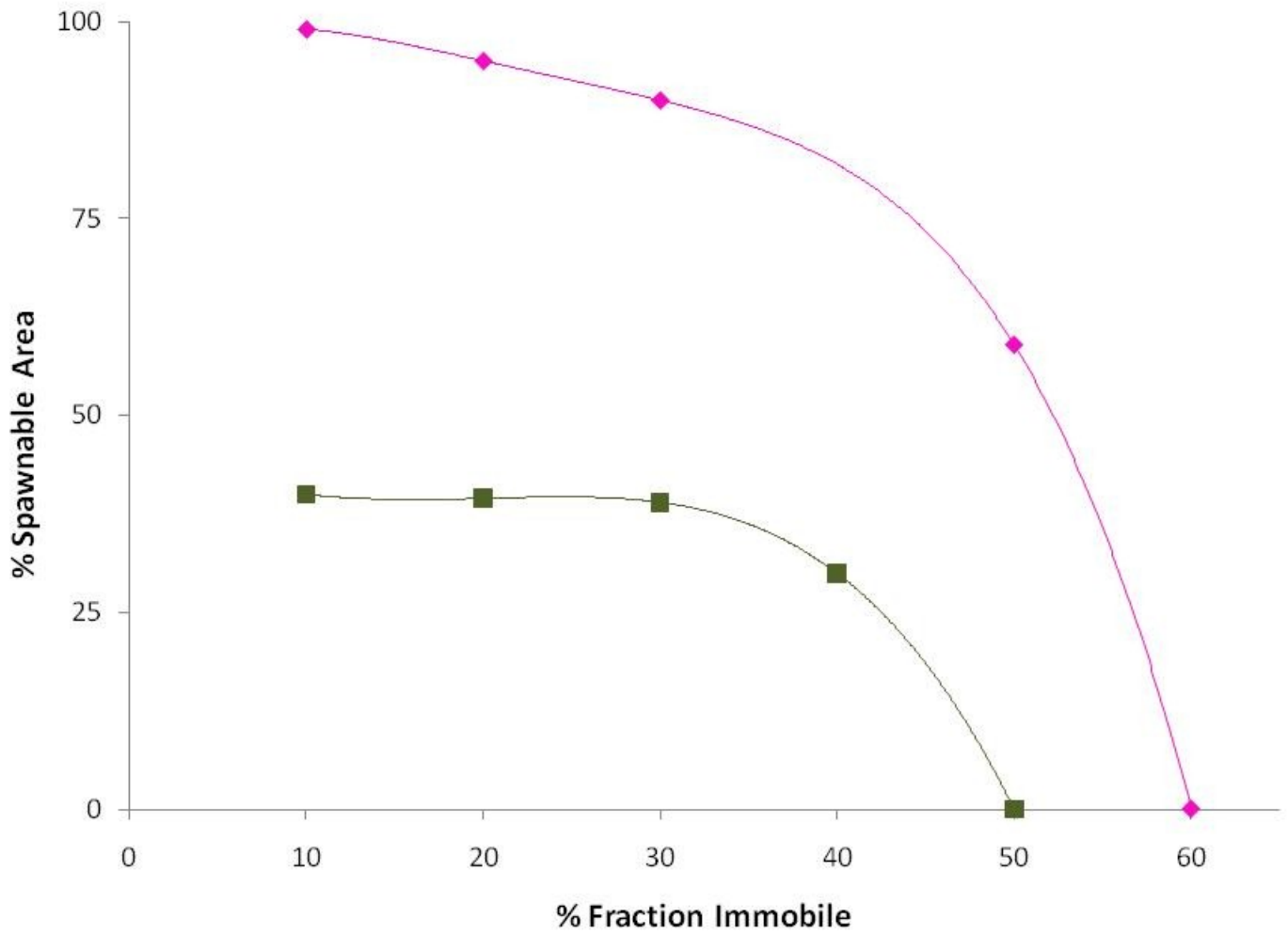
1755

1756 Figure 19. Conceptual graph of residual pool depth (Maximum depth – tail depth) pre and post
1757 dam removal in the Elwha River. The goal is to capture change in the depth of pool habitats and
1758 the change in streambed size due to the influx of sediment that occurs with dam removal.



1759

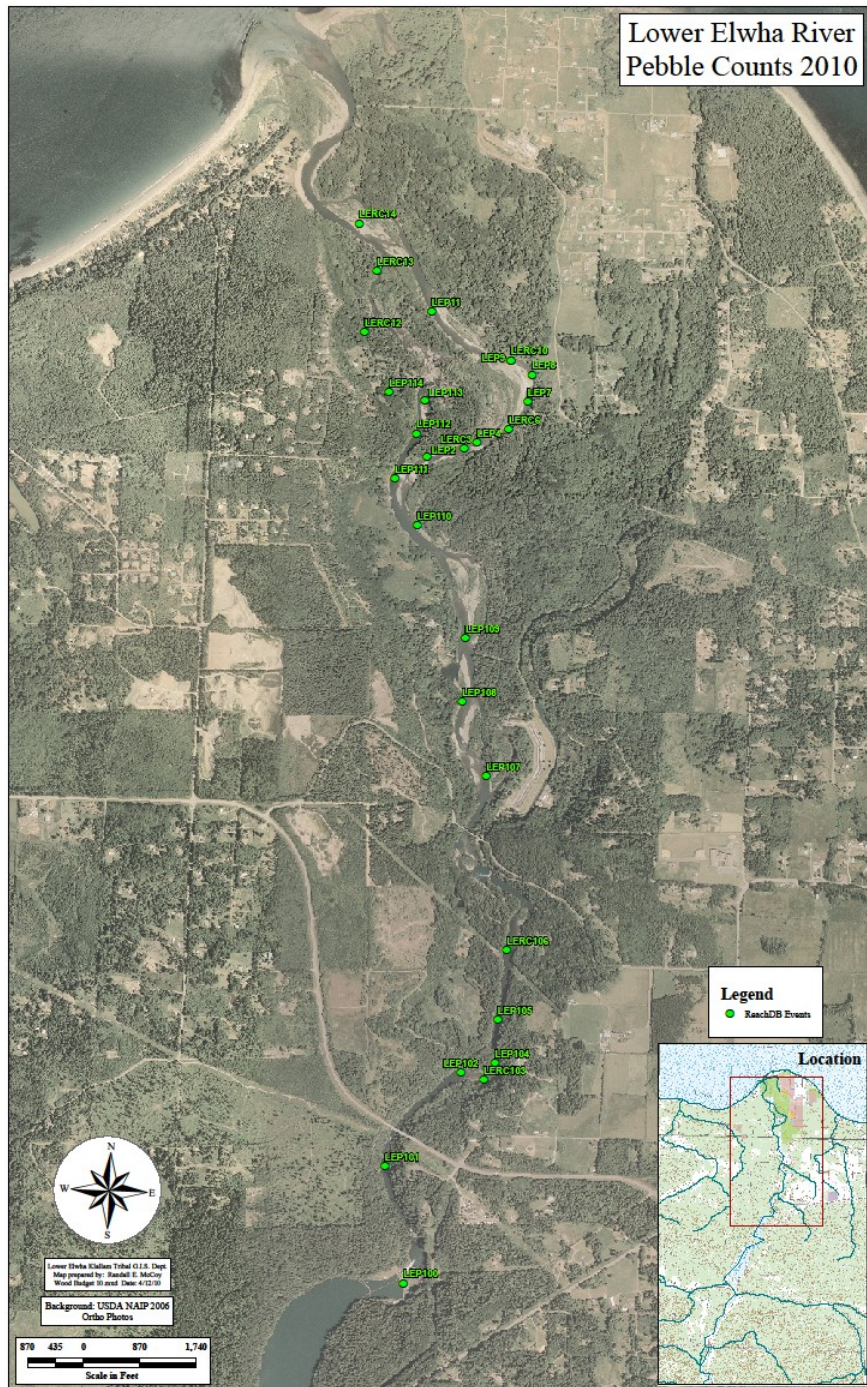
1760 Figure 20. Percent area spawnable as a function of the percent fraction that is immobile. Adopted
 1761 from Wooster et al. 2009. Percent spawnable for pink salmon is $y = -4E-05 * \%fraction\ immobile^4$
 1762 $+ 0.0036 * \%fraction\ immobile^3 - 0.1233 * \%fraction\ immobile^2 + 1.3548 * \%fraction\ immobile +$
 1763 94.55 . Percent spawnable for Chinook salmon is $y = -2E-05 * \%fraction\ immobile^4 + 0.0002 *$
 1764 $\%fraction\ immobile^3 = 0.0281 * \%fraction\ immobile^3 - 0.7958 * \%fraction\ immobile + 45.10$.



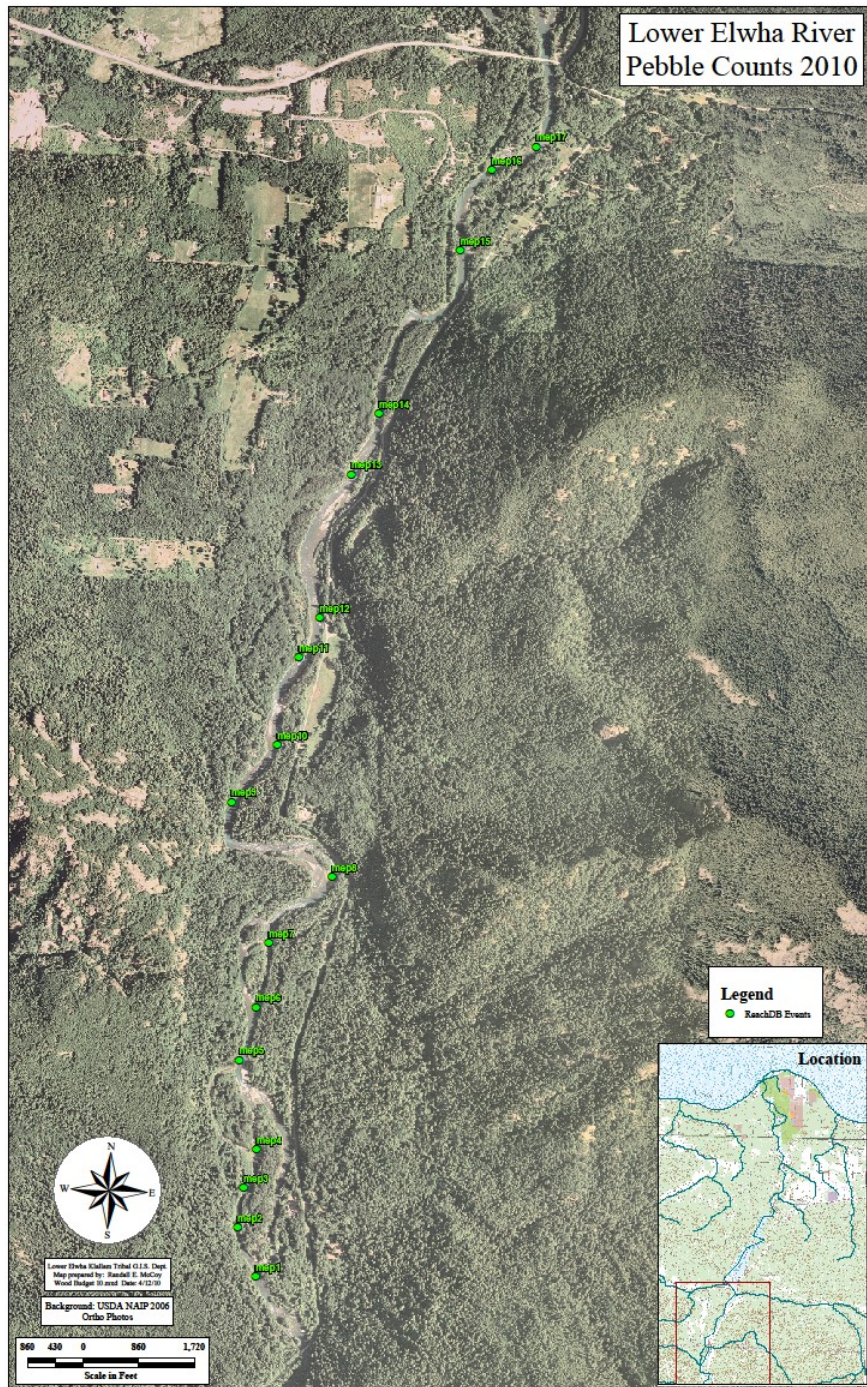
1766 Figure 21. Map of residual pool depth and pebble count locations in the a. Lower and b. Middle
 1767 Elwha River.

1768

1769 a.



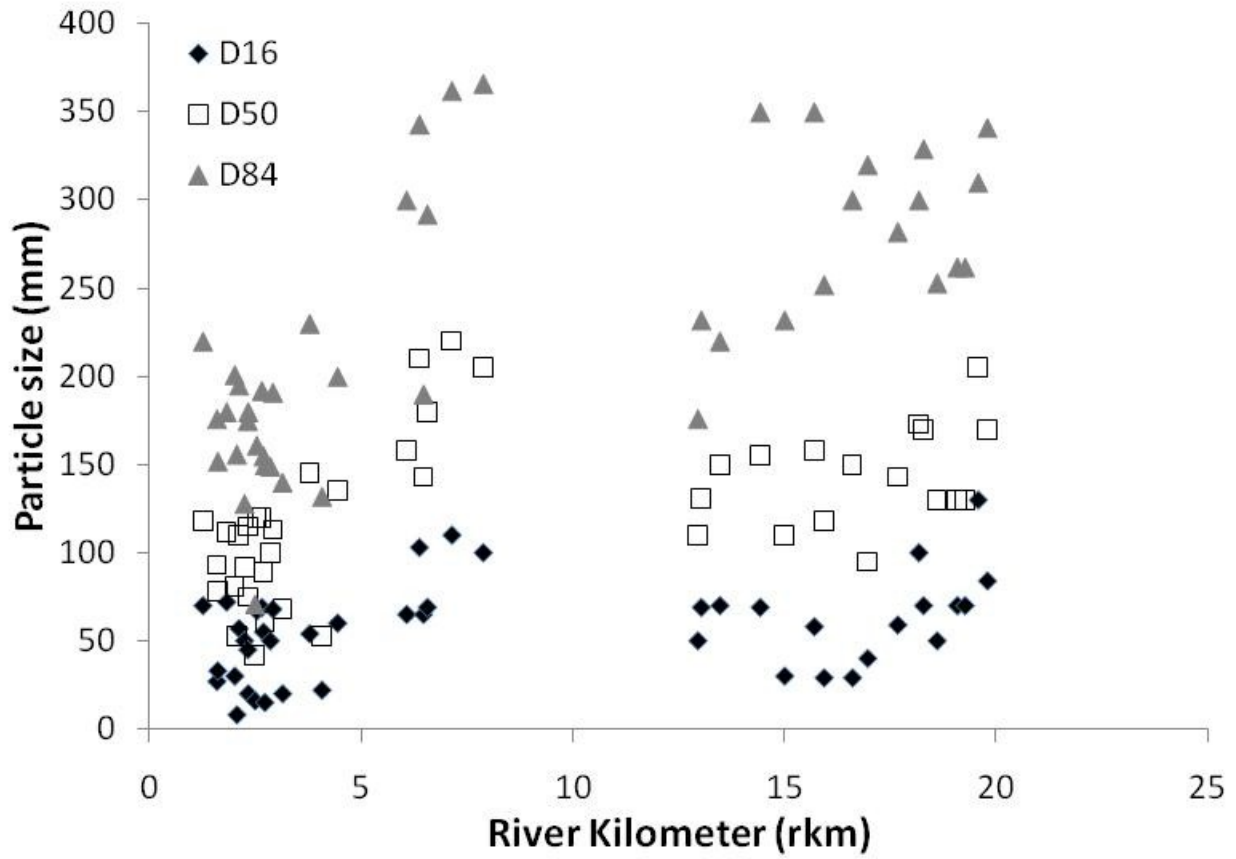
- 1770
- 1771
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- 1773
- 1774 b.



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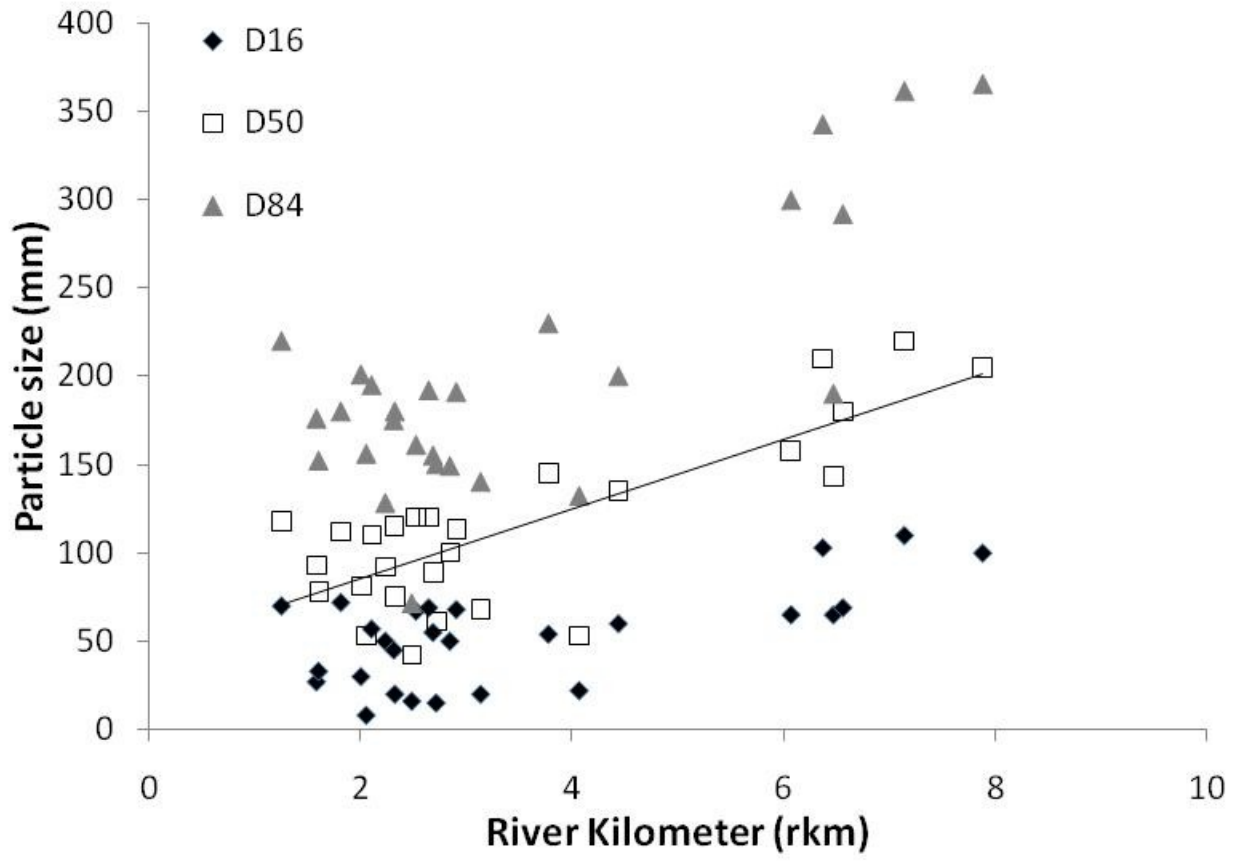
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1777 Figure 22. a. Trend in stream bed particle size in Middle and Lower Elwha River. b. Trend in
1778 stream bed particle size in the Lower Elwha. $D_{50} = 19.77 (Rkm) + 45.51, R^2 = 0.63$. c. Trend in
1779 stream bed particle size in the Middle Elwha. $D_{50} = 4.88 (Rkm) + 61.13, R^2 = 0.17$.
1780 a.



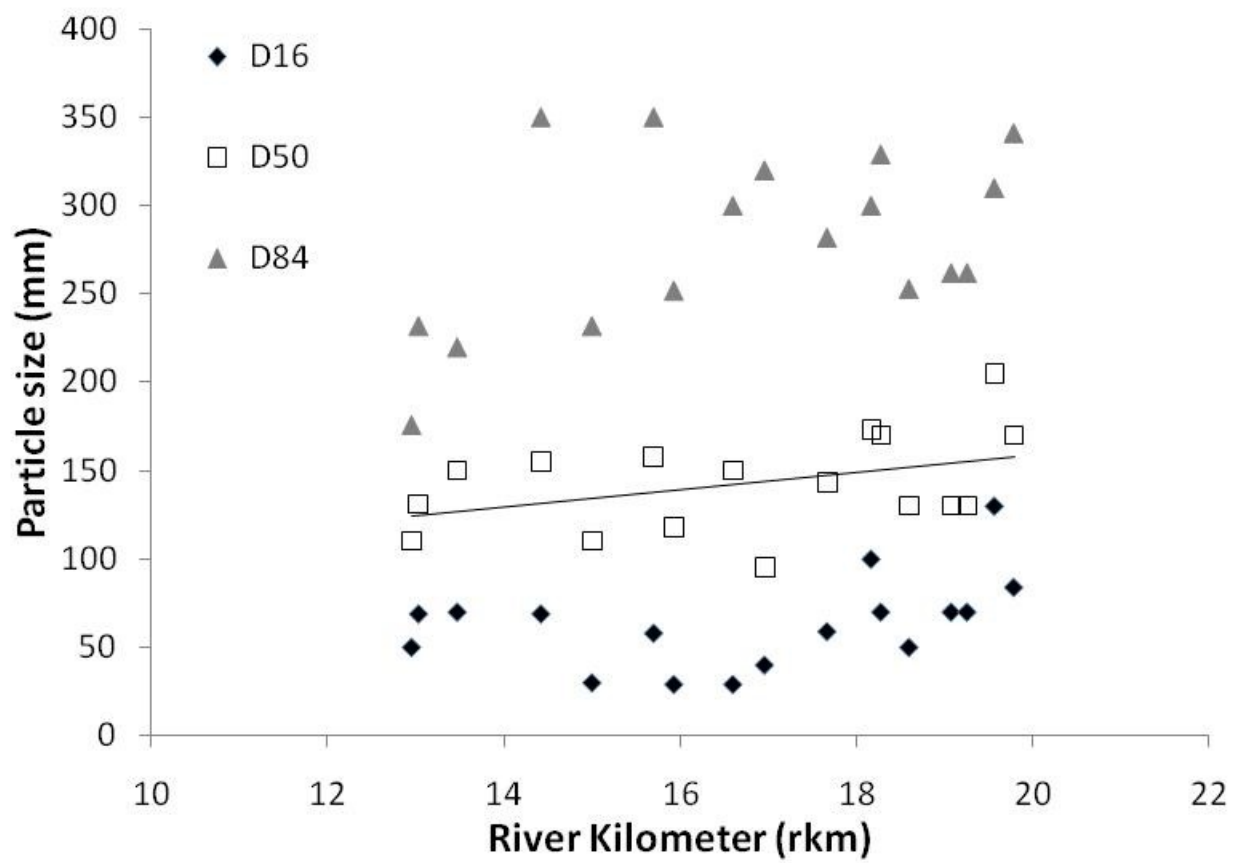
1781

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1783 b.
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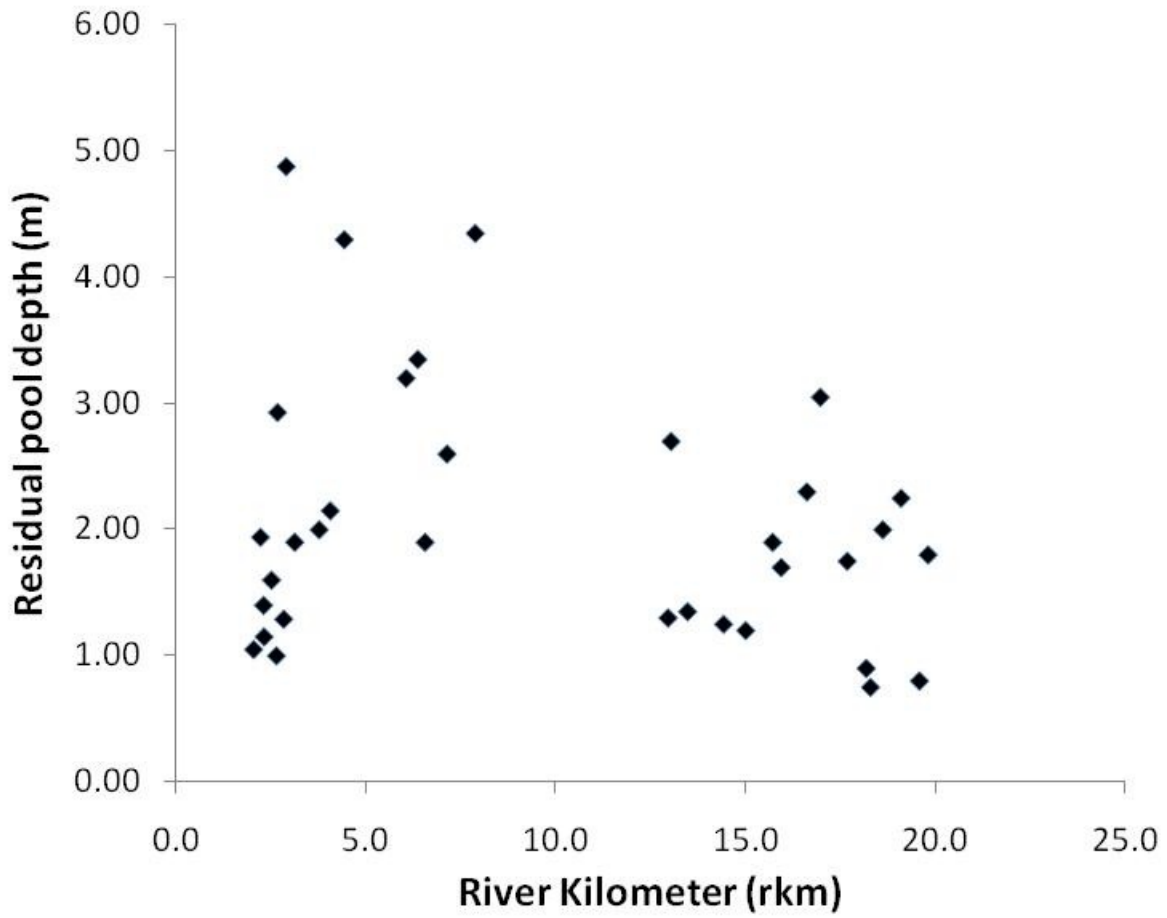
1786
1787 c.
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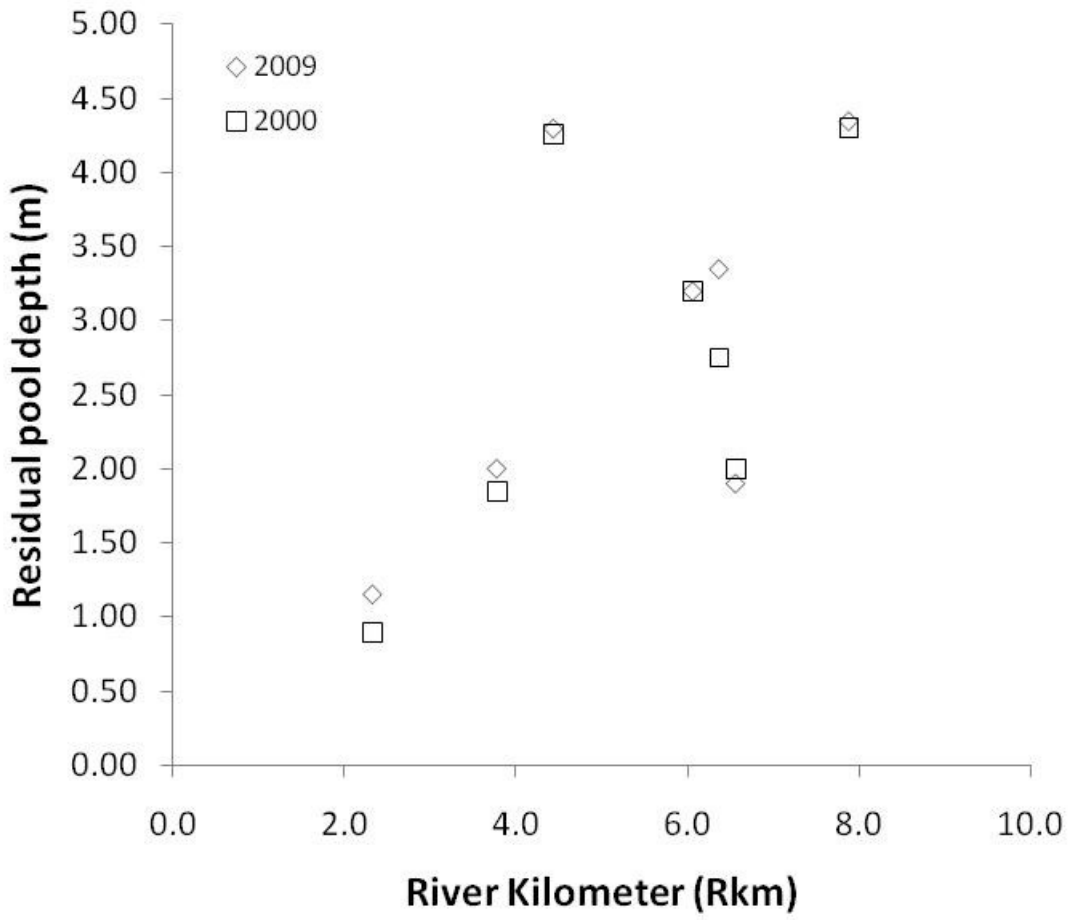
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Figure 23. Residual pool depth in the Lower and Middle Elwha River.



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Figure 24. A comparison of residual pool in the Lower Elwha River – 2000 v. 2009.



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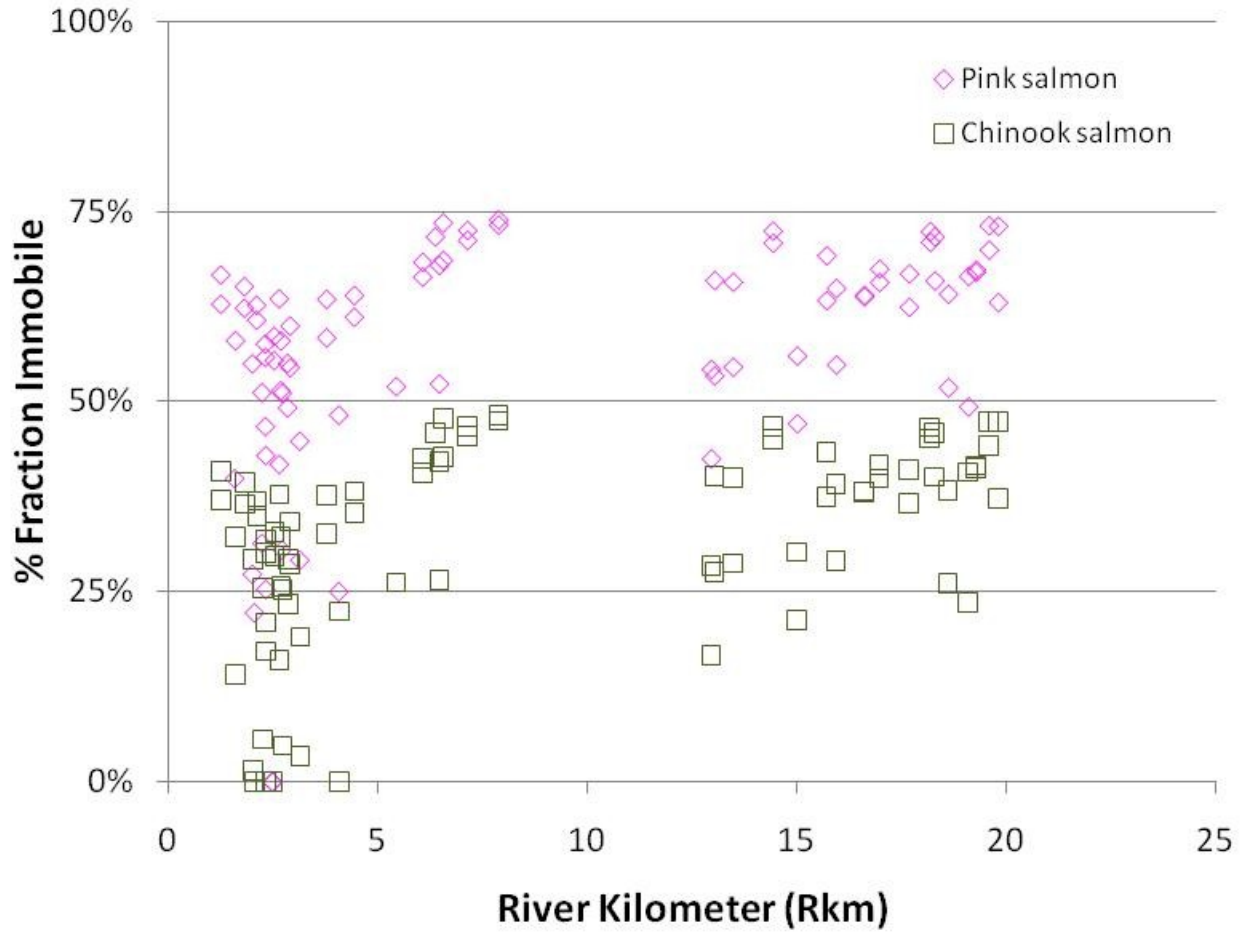
1799

1800 Figure 25. Percent fraction immobile by species in the Middle and Lower Elwha River.

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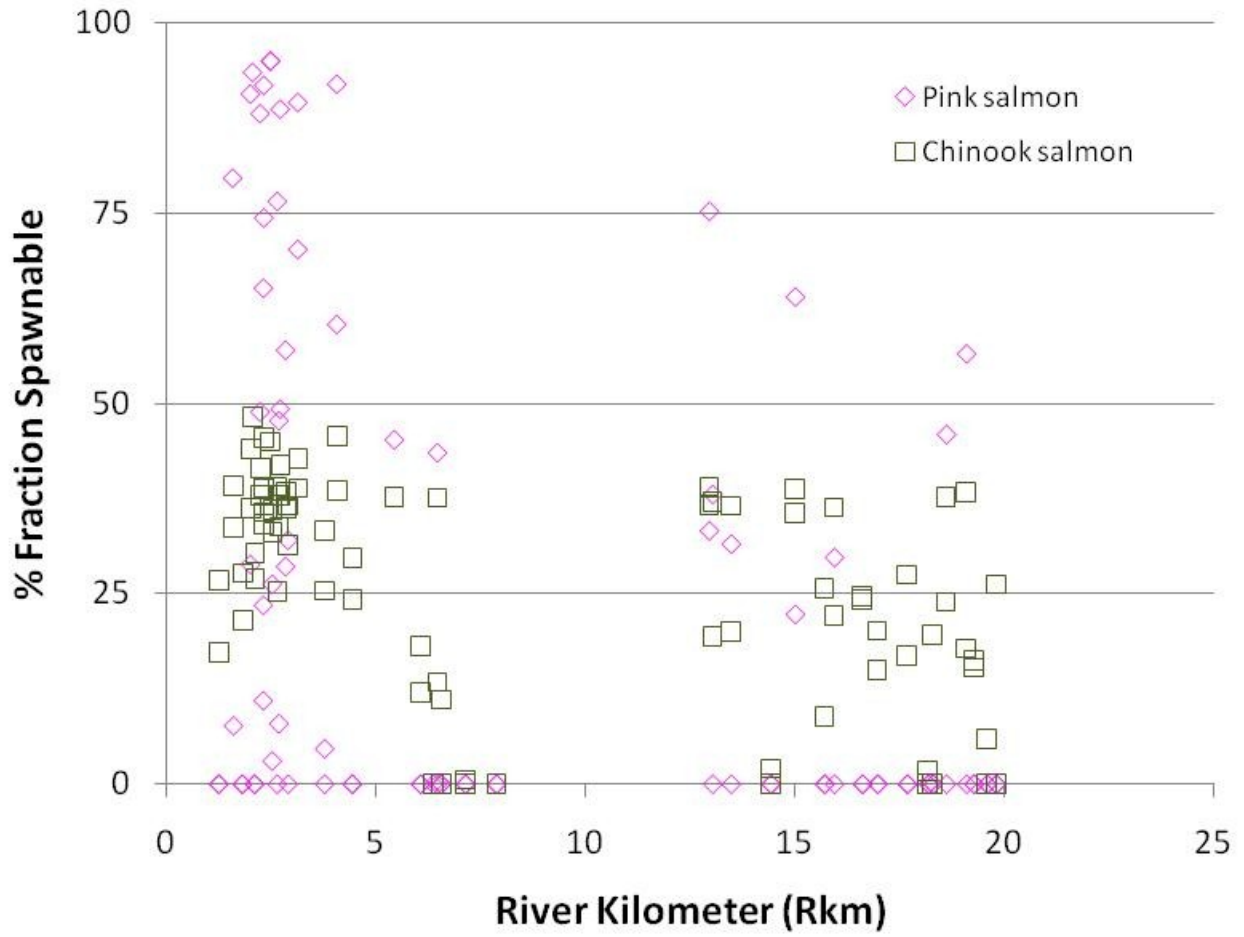


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Figure 26. Percent spawnable by species in the Middle and Lower Elwha River.



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1819 **Appendices**

1820 **Appendix A - Adult enumeration - Using imaging sonar to count adult Chinook passage**
1821 **into the lower river**

1822 On the Elwha, NOAA fisheries and the Lower Elwha Klallam Tribe (LEKT) have run an
1823 imaging SONAR project to enumerate summer Chinook in 2008 and 2009 and winter steelhead
1824 in 2009. A multi-beam, imaging SONAR was active in the Hunt's road side channel (RKM 2.5)
1825 from August 16th to September 25th, 2008 and from June 1st to September 30th, 2009. The
1826 SONAR setup includes a BlueView Technologies, Proviewer (900 kHz, P900-20) imaging
1827 SONAR unit powered by an array of four solar panels which continuously charge six 12-volt
1828 batteries. Blueview proprietary software records hour long (1 GB) files onto a hard drive which
1829 is downloaded every 2 weeks. The SONAR project records an extraordinary amount of data; ~
1830 1000 hours in 2008 and ~2500 hours in 2009, therefore the data must be subsampled. Ten minute
1831 sections were counted from each even hour of data and counts were bootstrapped to fill in the
1832 uncounted portions of the data (Lilja et al. 2008). In addition to raw count information, data on
1833 fish size and the general quality of the fish image was collected for the 2009 data. Multiple
1834 observers also analyzed specific sets of data in 2009. This additional data will allow us to add
1835 confidence intervals to our estimates and determine the major sources of error in our analysis.

1836

1837 **Appendix B - Juvenile and adult enumeration - An analysis of existing baseline conditions**
1838 **of relative juvenile and adult salmonid distribution and abundance across the Elwha River**
1839 **(Taken from a paper that is currently being written by Sam Brenkman, Jeff Duda, Roger**
1840 **Peters, Christian Torgerson, Ethan Welty, and George Pess)**

1841 Introduction

1842 Snorkeling provides the best balance of effectiveness and efficiency for enumerating fish over
1843 long stretches of small to large streams with deeper, more complex habitat. Snorkeling can also
1844 be used to identify associations between a few species and river habitat at the reach or section
1845 scale. Snorkeling extensive sections of river allows us to develop a baseline condition of relative
1846 juvenile and adult salmonid distribution and abundance across the entire Elwha River, including
1847 the largest section – the area above both dams. This baseline information is critical to help in
1848 identifying the correlation between habitat characteristics, fish species, and fish size class and
1849 will help determine why specific patterns occur pre and post dam removal. It will also help
1850 identify how fish response is related to habitat condition change over time.

1851 Aquatic environments are inherently difficult to sample, and large systems such as the Elwha
1852 River pose numerous challenges to collecting information about fish populations. The use of
1853 traditional fisheries methods is particularly challenging in the Elwha River because of prolonged
1854 periods of high flow, low water visibility from glacial melt, difficult access in rugged wilderness
1855 areas, and restrictions on allowable sampling methods in National Park waters. These challenges
1856 are compounded by the presence of migratory fishes, whose extensive movements in rivers add
1857 complexity to sampling.

1858 We conducted a 65 rkm survey of fish communities and habitat conditions to provide baseline
1859 data and facilitate inferences about salmon recolonization throughout the watershed following
1860 dam removal. The snorkel surveys were used to characterize the fish assemblage structure,
1861 spatial distribution, and relative abundances of salmonids in the Elwha River from the
1862 headwaters to the sea in August, 2007 and 2008. Our goal was to provide a basin-scale
1863 assessment of the fish populations and habitat conditions throughout the Elwha River over two
1864 consecutive years. Specific objectives were to: a) determine the spatial extent of existing
1865 salmonids in the main stem river from rkm 65 to rkm 0; b) assess the patterns of species
1866 composition, abundance, and length classes across a longitudinal gradient of consecutive habitat
1867 units; and c) assess longitudinal distribution of major habitat features throughout the river (e.g.,
1868 habitat types, large woody debris, substrate types).

1869 Methods

1870 *Longitudinal Surveys of Fish Species*

1871 We conducted spatially continuous snorkel surveys throughout 65 rkm of the Elwha River during
1872 summer low-flow periods in August, 2007 and in August and September, 2008. Snorkel surveys

1873 can provide precise and reliable estimates of fish abundance (Northcote and Wilkie 1963, Schill
1874 and Griffith 1984, Thurow 1994), provide longitudinal profiles of fish distributions (Torgersen et
1875 al. 2006), and are useful in the simultaneous assessment of multiple species. Useful in deep, clear
1876 rivers where the effectiveness of other methods is limited, snorkeling is often the only approach
1877 possible in roadless or wilderness areas because of the relatively small amount of equipment
1878 required (Thurow 1994). The upper sections of the Elwha River could not be effectively
1879 surveyed by boat or other wading techniques due to the depth of pools and difficult access.
1880 Additionally, the passive nature of the technique (e.g., no handling of fish) is conducive to
1881 sampling protected fish stocks that inhabit National Park waters where invasive methods are less
1882 desired.

1883 In 2007 and 2008, 20 surveyors were divided into teams of four and distributed throughout 65
1884 rkm. In each year, surveyors were professional biologists experienced in snorkel techniques and
1885 fish identification. To access remote sites in the uppermost portions of the watershed, we used
1886 pack mules to carry and distribute field sampling and camping equipment at strategically located
1887 base camps. Prior to the weeklong surveys, we also conducted aerial reconnaissance in a Cessna
1888 172 to demark log jams and other hazards along the river and conducted foot surveys to denote
1889 the upstream and downstream ends of remote canyons with flagging to increase safety.

1890 Two divers, one on each side of the river, proceeded downstream at the speed of the current and
1891 counted each species that was > 10 cm in length. Divers recorded length classes of bull trout and
1892 rainbow trout in categories of 10-20 cm, >20 -30 cm, >30 cm. Three divers were used in the
1893 widest sections of the river in-between the dams and downstream of Elwha Dam. The diver on
1894 the left bank (looking downstream) counted and recorded fish from the midpoint of the river
1895 channel to the left bank. The diver on the right bank counted fish from the midpoint of the river
1896 channel to the right bank. We did not survey Lake Mills and Lake Aldwell, and were unable to
1897 survey three canyon sections (ca. 10.4 rkm) rendered inaccessible by prohibitively steep slopes
1898 and dangerous river crossings.

1899 The primary targets were Pacific salmonids based on their relative abundance and ease of
1900 identification. When fish were observed in large aggregations or near wood jams, divers made
1901 two passes in their respective lanes and averaged the counts as necessary. Divers made frequent
1902 data recording stops (~every 100 m) to compare observations and minimize duplication of
1903 counts. Because of the difficulty in distinguishing between cutthroat trout and rainbow trout
1904 underwater, counts were combined as cutthroat/rainbow trout (hereafter trout). The snorkeling
1905 procedures were consistent in 2007 and 2008.

1906 *Longitudinal Surveys of Aquatic Habitat*

1907 In 2008, we conducted a spatially continuous habitat survey throughout the entire river
1908 concurrent with the fish survey. Following the two divers counting fish, two habitat surveyors
1909 walked downstream along gravel bars and measured physical habitat variables including:

1910 channel type (main, secondary, or side channel), habitat type (riffle, pool, glide-like riffle, and
1911 glide-like pool) according to Bisson et al. (1982), habitat unit length (m) and wetted width (m).
1912 Wetted width was measured at three locations for every unit, approximately 25 percent, 50
1913 percent and 75 percent of the distance from the upstream end to downstream end of the unit. All
1914 distances were measured using laser range finders (TruPulse 200, Laser Technology Impulse).

1915 We measured the extent of overhanging vegetation, boulders and log jams (fish cover) in each
1916 habitat unit. The percent of bank habitat with vegetation overhanging the wetted channel within
1917 30 cm of the water surface was estimated visually. The percent of the habitat unit surface area
1918 with boulder cover (>256 mm) was also estimated visually. The number of wood pieces or
1919 aggregations (i.e. logjams) with wood pieces >10cm diameter base height was counted and the
1920 surface area of these jams was measured using laser range finders. The two divers counting fish
1921 relayed the dominant and subdominant substrate types and estimated the mean and maximum
1922 depth (m) of each habitat unit. Substrate was classified according to Cummins (1962) as bedrock
1923 (including hardpan clay), boulder (> 256 mm, including riprap), cobble (64-256 mm), gravel (2-
1924 64 mm), sand (< 2 mm), silt (< 0.6 mm) or organic debris.

1925 A handheld GPS unit (Garmin GPSMap 60CSx) was used to map locations of each habitat unit,
1926 and the GPS tracklog function allowed the continuous collection of position data throughout the
1927 entire 65 rkm. Waypoints were recorded at the upstream and downstream ends of each habitat
1928 unit. During times of poor satellite geometry, where accurate position fixes were not possible,
1929 habitat unit lengths were measured with the laser rangefinder.

1930 *Spatially Continuous Fish and Habitat Relationship Analysis*

1931 We used several steps to correlate fish species abundance with physical habitat characteristics in
1932 the Elwha River Basin. We used species abundance (fish/km) as the response variable and
1933 stream habitat characteristics were the independent variables. We implemented a linear
1934 modeling approach using Akaike's Information Criterion, adjusted for small sample sizes
1935 (AICc), to determine which model best fit the data (Burnham and Anderson 2002). The
1936 difference between the AICc of a candidate model and the one with the lowest AICc provided
1937 the ranking metric ($\Delta AICc$). Generally speaking, $\Delta AICc$ between 0 and 4 indicates substantial
1938 support for a model being as good as the best approximating model, $\Delta AICc$ between 4 and 7
1939 represents less support, and $\Delta AICc$ of greater than 7 indicates very little support for a candidate
1940 model relative to the best model (Burnham and Anderson 2002). Akaike weights (w_i) were
1941 calculated, representing the strength of evidence in favor of model i being the best model. The
1942 ratio of Akaike weights (w_i / w_j) indicates the plausibility of the best-fitting model compared to
1943 other models (Burnham and Anderson 2002). Models with an evidence ratio of 10 or less were
1944 considered plausible (Burnham and Anderson 2002). If models were not clearly the "best"
1945 model based on the preceding criteria, then models within three AICc were considered
1946 competing models and results were averaged to determine the maximum likelihood estimate for

1947 the intercept and each of the independent variables that are part of the models (Burnham and
1948 Anderson 2002, Haring and Fausch, 2002).

1949 Results

1950 *Spatially Continuous Fish and Habitat Relationships*

1951 Correlating rainbow trout and bull trout abundance with habitat attributes from the different
1952 streams in the Elwha River basin revealed that several variables were consistently positively
1953 correlated including the amount of habitat area, substrate type, instream cover variables, and
1954 river section (Tables B1 through B3). Almost all the rainbow trout models (total and each size
1955 class) with the best AICc scores included total habitat area (Tables B1 and B3). The amount of
1956 boulder area or amount of instream boulder cover, log jam area or the number of log jams, and
1957 river section were in the majority of the best rainbow trout candidate models (Tables B1 and B3).
1958 Total habitat area and gravel (%) were in the all the bull trout candidate models with the best
1959 AICc scores (Tables B2 and B3). River section and the total number of log jams were the only
1960 other independent variables that were in the bull trout candidate models with the best AICc
1961 scores.

1962 The relationship between rainbow trout/km and total habitat area and boulders (%) was always
1963 positive, while there was always a negative correlation between rainbow trout/km and river
1964 section or instream boulders (%) (Table B3). Log jam area and the number of log jams were, for
1965 the most part, positively correlated to rainbow trout/km (Table B3). Total habitat area, river
1966 section, and gravel (%) were positively correlated to bull trout/km, while the number of log jams
1967 was negatively correlated to bull trout/km (Table B3).

1968 Discussion

1969 *Spatially Continuous Fish and Habitat Relationships*

1970 Habitat area, the amount of in-channel cover, and streambed particle size were important
1971 descriptive variables related to the abundance of rainbow and bull trout. An increase in habitat
1972 area alone, without changes to habitat types or increased resilience to disturbance, can result in
1973 an increase in the occurrence and abundance of animals (Steffan-Dewenter 2003). Bull trout
1974 persistence has previously been positively correlated to an increase in habitat area (Watson and
1975 Hillman 1997, Dunham and Reiman 1999), and has also been hypothesized to allow existing
1976 populations to be less vulnerable to natural and anthropogenic disturbance. This can reduce the
1977 potential for extinction, increase the potential for persistence, and result in larger populations in
1978 larger habitat areas (Lande 1993, Dunham Reiman 1999). An increase in habitat area has also
1979 been hypothesized to result in a greater diversity of habitat types that may be needed to promote
1980 life-stage specific survival of enough individuals to sustain populations (Haring and Fausch
1981 2002). The occurrence and abundance of other adult salmonid species such as pink
1982 (*Oncorhynchus gorbuscha*), chum (*O. keta*), and Chinook salmon (*O. tshawytscha*) has also been

1983 correlated to increasing habitat area in Alaska (Pess 2009) and throughout the Pacific Rim
1984 (Liermann et al. 2009).

1985 The amount of in-channel cover, regardless of type (e.g., boulder, wood, depth etc) has
1986 consistently been shown to be an important correlate to salmonid fish densities (Shirvell 1990,
1987 Fausch 1993, Beechie et al. 2005). *O. mykiss* have been shown to prefer boulder cover, overhead
1988 cover (Shirvell 1990; Fausch 1993), and wood cover (Beechie et al. 2005). The correlation
1989 between larger cover types and *O. mykiss* densities may, in part, be spurious and the result of
1990 competition with other species, or an artifact of their ability to occupy higher-velocity habitats
1991 (Bisson et al. 1988). Thus *O. mykiss* may choose habitats based on characteristics other than
1992 cover type, and simply the predominance of cobble– boulder cover (more than 50% of sample
1993 points with that cover type) suggests a preference that may not exist (Beechie et al. 2005).

1994

1995 **Juvenile enumeration – An analysis of existing baseline conditions of relative juvenile and**
1996 **adult salmonid distribution and abundance across the Elwha River**
1997

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2066 Management 17:237–252.

2067 **Tables and Figures**

2068 Table B1. Model selection results for factors that affected Rainbow trout abundance (rainbow trout/km) in the Elwha River basin.
 2069 Models are ranked from most plausible ($\Delta AIC_c=0$) to least plausible; p is the number of parameters. The ratio of Akaike weights
 2070 (w_i/w_i) indicates the plausibility of the best fitting model (w_i) compared to other models (w_i).

Rainbow trout	Model	Log Likelihood	p	ΔAIC_c	Akaike weight (w_i)	R^2	w_i/w_i
Total	Number of log jams, total habitat area, boulders (%)	-220.99	4	0.00	0.94	0.83	1.000
>10cm & < 20cm	River section, log jam area, instream boulder cover (%)	-170.84	4	0.00	0.28	0.86	1.000
	River section, log jam area, mean depth	-171.15	4	0.62	0.21	0.86	1.363
	River section, log jam area, boulders (%)	-171.76	4	1.84	0.11	0.86	2.509
	River section, log jam area	-173.36	3	2.55	0.08	0.84	3.578
	River section, bull trout abundance, log jam area	-172.21	4	2.74	0.07	0.85	3.935
	River section, log jam area, SA_SI	-172.39	4	3.10	0.06	0.85	4.711
	River section, log jam area, gravel (%)	-172.59	4	3.49	0.05	0.85	5.726
>20cm & < 30cm	Habitat area, boulders (%), instream overhanging vegetation (%)	-203.84	4	0.00	0.73	0.74	1.000
>30cm & < 40cm	River section, boulders (%), instream boulders (%)	-172.31	4	0.00	0.39	0.77	1.000
	Total habitat area, boulders (%), instream boulders (%)	-172.38	4	0.14	0.36	0.77	1.072
	Boulders (%), instream boulders (%), wetted width	-173.77	4	2.93	0.09	0.76	4.328
> 40cm	Log jam area, total habitat area, instream boulders (%)	-117.63	4	0.00	0.43	0.73	1.000
	Total habitat area, instream boulders (%), wetted width	-118.74	4	2.23	0.14	0.71	3.049

2071 Table B2. Model selection results for factors that affected bull trout abundance (bull trout/km) in the Elwha River basin. Models are
 2072 ranked from most plausible ($\Delta AICc=0$) to least plausible; p is the number of parameters. The ratio of Akaike weights (w_l/w_i) indicates
 2073 the plausibility of the best fitting model (w_l) compared to other models (w_i).
 2074

Bull trout	Model	Log Likelihood	p	$\Delta AICc$	Akaike weight (w_i)	R^2	w_l/w_i
Total	River section, total habitat area, gravel (%)	-129.87	4	0.00	0.58	0.45	1.000
	Number of log jams, total habitat area, gravel (%)	-131.74	4	3.74	0.09	0.40	6.488
>40cm	River section, total habitat area, gravel (%)	-127.02	4	0.00	0.50	0.47	1.000
	Number of log jams, total habitat area, gravel (%)	-127.94	4	1.84	0.20	0.45	2.509

2075

2076 Table B3. Maximum-likelihood estimates of intercept and slope parameters for the “best approximating” models predicting rainbow
 2077 trout and bull trout abundance. a. rainbow trout total and >10cm & <20cm. b. rainbow trout >20cm & <30cm, >30 & <40cm, and
 2078 >40cm. c. bull trout. Standard errors are in parentheses.
 2079 a.
 2080

Rainbow trout	Model	Intercept	Total habitat area	River section	Boulders (%)	Log jams	Log jam area	Gravel	Instream boulders	Instream overhanging vegetation	Mean depth	Wetted width	Bull trout	SA_SI
Total	Number of log jams, total habitat area, boulders (%)	-111.96 (15.64)	0.003 (0.0004)	--	1.375 (0.280)	4.034 (0.915)	--	--	--	--	--	--	--	--
>10cm & <20cm	River section, log jam area, instream boulder cover (%)	36.555 (7.387)	--	-15.225 (2.644)	--	--	0.015 (0.001)	--	0.280 (0.127)	--	--	--	--	--
	River section, log jam area, mean depth	18.788 (12.988)	--	-12.057 (3.125)	--	--	0.016 (0.001)	--	--	--	13.845 (6.736)	--	--	--
	River section, log jam area, boulders (%)	30.227 (9.571)	--	-13.164 (2.997)	0.131 (0.076)	--	0.016 (0.001)	--	--	--	--	--	--	--
	River section, log jam area	41.078 (7.421)	--	-15.426 (2.764)	--	--	0.015 (0.001)	--	--	--	--	--	--	--
	River section, bull trout abundance, log jam area	40.914 (7.322)	--	-14.936 (2.747)	--	--	0.015 (0.001)	--	--	--	--	--	-0.457 (0.313)	--
	River section, log jam area, SA_SI	43.288 (7.532)	--	-17.144 (3.022)	--	--	0.015 (0.001)	--	--	--	--	--	--	0.702 (0.523)
	River section, log jam area, gravel (%)	39.821 (7.457)	--	-14.057 (2.978)	--	--	0.015 (0.001)	-1.05 (0.088)	--	--	--	--	--	--

2082 b.
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Rainbow trout	Model	Intercept	Total habitat area	River section	Boulders (%)	Log jams	Log jam area	Gravel	Instream boulders	Instream overhanging vegetation	Mean depth	Wetted width	Bull trout	SA_SI
>20cm & < 30cm	Habitat area, boulders (%), instream overhanging vegetation (%)	-53.24 (1.471)	0.002 (0.0003)	--	0.656 (0.167)	--	--	--	--	1.471 (0.465)	--	--	--	--
>30cm & <40cm	River section, boulders (%), instream boulders (%)	25.539 (8.778)	--	-7.994 (2.895)	0.741 (0.081)	--	--	--	-0.855 (0.145)	--	--	--	--	--
	Total habitat area, boulders (%), instream boulders (%)	-6.096 (4.665)	0.0004 (0.0001)	--	0.658 (0.097)	--	--	--	-0.731 (0.159)	--	--	--	--	--
	Boulders (%), instream boulders (%), wetted width	-6.246 (5.492)	--	--	0.644 (0.116)	--	--	--	-0.821 (0.155)	--	--	0.532 (0.249)	--	--
> 40cm	Log jam area, total habitat area, instream boulders (%)	-1.694 (1.362)	0.0003 (0.00003)	--	--	--	-0.0012 (0.0004)	--	-0.086 (0.039)	--	--	--	--	--
	Total habitat area, instream boulders (%), wetted width	-3.996 (1.458)	0.0002 (0.00005)	--	--	--	--	--	-1.228 (0.039)	--	--	0.247 (0.068)	--	--

2085 c.
2086
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Bull trout	Model	Intercept	Total habitat area	River section	Boulders (%)	Log jams	Log jam area	Gravel	Instream boulders	Instream overhanging vegetation	Mean depth	Wetted width	Rainbow trout	SA_SI
Total	River section, total habitat area, gravel (%)	-21.542 (5.874)	0.0003 (0.0001)	4.295 (1.541)	--	--	--	0.167 (0.035)	--	--	--	--	--	--
	Number of log jams, total habitat area, gravel (%)	-5.985 (2.246)	0.0002 (0.00005)	--	--	-0.245 (0.125)	--	0.210 (0.043)	--	--	--	--	--	--
>40cm	River section, total habitat area, gravel (%)	-21.45 (5.505)	0.0003 (0.00006)	4.067 (1.444)	--	--	--	0.164 (0.032)	--	--	--	--	--	--
	Number of log jams, total habitat area, gravel (%)	-6.68 (2.059)	0.0002 (0.00004)	--	--	-0.279 (0.114)	--	0.213 (0.039)	--	--	--	--	--	--

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2091 **Appendix C - Foodweb - Primary and secondary productivity trends**

2092 Introduction

2093 Primary and secondary producers serve vital roles in the structure and function of aquatic
2094 ecosystems. In medium and large rivers in particular ($\geq 4^{\text{th}}$ order), primary production by
2095 periphyton is a major food source for higher trophic levels (Thorp & DeLong 2002). Secondary
2096 producers (e.g. aquatic invertebrates) serve as a direct food source for fish and strongly influence
2097 nutrient cycling and primary productivity (Merritt & Cummins 1996; Wallace & Webster 1996).
2098 As periphyton and invertebrates are directly associated with the benthos, they are likely to be
2099 profoundly influenced by both the presence and removal of dams (Bednarek 2001; Doyle et al.
2100 2005; Thomson et al. 2005). The rapid response and recovery that periphyton and benthic
2101 invertebrates typically display to disturbance are also well suited to monitoring efforts seeking to
2102 capture ecological response trajectories to dam removal (Shannon et al 2001; Doyle et al. 2005).
2103 Along with fish, periphyton and benthic invertebrates are the best studied and most commonly
2104 included taxa in stream and river biological assessment protocols (Davis & Simon 1995; Barbour
2105 et al. 1999; Moulton et al. 2002). Thus, much is known about their biology, how they respond to
2106 different types of disturbance, and many regional datasets exist for comparative purposes.
2107

2108 In the Elwha River, the first reported study of benthic invertebrates was done by the University
2109 of Oregon in a report to the Lower Elwha Tribal Council (Li 1990). This work was expanded in
2110 the mid 1990's with a survey conducted by the USGS Washington Water Science Center that
2111 examined 26 sites across the river basin (Munn et al 1996). In 2004, benthic invertebrate
2112 monitoring on the Elwha was taken up again by NOAA's Northwest Fisheries Science Center
2113 and USGS's Western Fisheries Research Center, who added periphyton as an additional sample
2114 parameter and sampled 52 sites over three years (Figure C1; Morley et al. 2008). Results from
2115 the three studies are similar. Morley et al. (2008) did not observe major shifts in total taxa
2116 richness across regulated and unregulated river sections, but did detect distinct differences in
2117 benthic invertebrate taxonomic composition above the dams compared to sites between and
2118 below (Figure C2). Similar patterns were observed by Munn et al. (1996). Periphyton biomass
2119 was consistently higher in regulated than unregulated sections (Morley et al. 2008)—a pattern
2120 though to reflect a high abundance of filamentous algae related to increased water temperature
2121 and water clarity, and decreased bed movement (Li 1990; Munn and Brusven 2004).
2122

2123 Another focus of foodweb research in the Elwha River has been on changes in nutrient dynamics
2124 following re-colonization by anadromous salmonids. With the majority of their body mass
2125 obtained at sea, adult salmon return to freshwater spawning grounds enriched with marine-
2126 derived nutrients (MDN). These MDN influence the productivity and ecology of freshwater
2127 ecosystems via deposition of carcasses, gametes, and excretion of waste when salmon complete
2128 their life cycle (Gende et al. 2002; Schindler et al. 2003). Understanding the dynamics associated
2129 with reintroduction of anadromous salmonids and the nutrient subsidy provided to their
2130 spawning habitats and surrounding ecosystems in an important component of evaluating the

2131 recovery of the Elwha River ecosystem, as well as the restoration of other salmon-bearing rivers.
2132 Tracing the movement and magnitude of MDN inputs into freshwater and riparian ecosystems is
2133 frequently done with stable isotope analysis, a technique which relies upon measuring the
2134 isotopic ratio of carbon and nitrogen heavy stable isotopes (more prevalent in marine
2135 environments) to their lighter counterparts (Fry 2006). In an extensive survey conducted from
2136 2004-2006 across the Elwha basin, Duda et al (2010) found that $\delta^{15}\text{N}$ was significantly higher in
2137 fish, stoneflies, black flies, periphyton, and macroalgae where salmon still have access (Figure
2138 C3). Fish and chloroperlid stoneflies were enriched in $\delta^{13}\text{C}$, but the values were more variable
2139 than in $\delta^{15}\text{N}$. For some taxa, there were also differences between the two river sections that lack
2140 salmon, suggesting that factors other than marine-derived nutrients are structuring longitudinal
2141 isotopic profiles. Water chemistry analyses confirmed earlier reports that the river is oligotrophic
2142 (Munn et al. 1999).

2143
2144 All of the above studies serve an important purpose of establishing baseline datasets to which
2145 post dam-removal comparisons can be made. Morley et al. (2008) and Duda et al. (2010) also
2146 serve as examples of the importance of standardizing data collection protocols, coordinating field
2147 collections among multiple collaborators, and incorporating detailed metadata at all steps along
2148 the way. Some examples of this documentation are found in the appendix of this report (e.g.,
2149 Access database, Google Earth map files). From the studies described above, some useful
2150 foodweb metrics have emerged, and some data gaps remain. In Table C1 and Table C2 we focus
2151 on the question of how the presence of the Elwha dams has affected primary and secondary
2152 productivity and identify what foodweb research questions are currently addressed by ongoing
2153 monitoring efforts, and what questions are not being studied. We conclude with
2154 recommendations for appropriate foodweb response metrics for the Elwha and other dam
2155 removal monitoring efforts, and provide brief logistical information related to labor, time, and
2156 funding requirements at the current level of baseline monitoring.

2157 2158 Discussion

2159 *Recommendations for protocol use at Elwha and pre-dam removal conclusions*

2160 The suite of foodweb metrics that have been collected thus far in baseline studies on the Elwha
2161 should be continued and expanded upon as we move closer to post dam-removal monitoring.
2162 Metrics that are highly variable (e.g., standing crop of periphyton) should be supplemented by
2163 measures of rates and processes (e.g., algal growth rates and nutrient limitations status).
2164 Sampling should also be expanded beyond the late summer index period to capture natural
2165 seasonal variability. Greater effort should be made to link foodweb monitoring with fish
2166 monitoring efforts; for instance, by incorporating the collection of invertebrate drift and fish diet
2167 samples into ongoing monitoring efforts. For data gaps that are not currently being addressed, we
2168 recommend pursuing additional research funds and seeking to involve other researchers with
2169 complimentary expertise. Emphasis on methodological standardization and metadata
2170 development should continue on the Elwha, as well as across other dam removal monitoring

2171 efforts. An ultimate goal of Elwha dam removal monitoring is the testing of hypotheses across
2172 larger spatial and temporal scales.

2173

2174 The current foodweb monitoring described above can be accomplished with a crew of 2-3. Two
2175 people are ideal for benthic invertebrate sampling, while only one is needed for periphyton and
2176 water chemistry. If sample sites are relatively nearby, a 3 person crew can typically sample 3
2177 sites in a day. Equipment costs are relatively low (< \$1,000 to put together a complete sampling
2178 kit). With the exception of benthic invertebrate taxonomy, sample processing costs are generally
2179 < \$25 per sample. It is typically most efficient and cost effective to send invertebrate samples to
2180 professional taxonomy labs for analysis. Cost per sample ranges from \$200-400 depending on
2181 level of taxonomic resolution and total number of organisms counted. Measurements of algal
2182 growth rates and nutrient limitation status can also be done with a crew of two. Equipment costs
2183 are again low (< \$750), but labor requirements greater due to the need for more frequent site
2184 visits, and pre and post sample processing requirements.

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2261 **Tables and Figures**

2262

2263 Table C1. Ongoing primary and secondary productivity research related to the Elwha River dam
 2264 removal.

Category	Metric	Analysis
Benthic invertebrates	Numerical density, Total taxa richness, Relative abundance EPT taxa vs. Chironomidae taxa	Analysis of similarities (ANOSIM), Pairwise similarity percentages (SIMPER)
Periphyton	Standing crop density (ash-free dry mass), Algal densities (chlorophyll-a), Algal growth rates Nutrient limitations (Morley et al., in prep; Sanderson et al. 2009)	Analysis of Variance (ANOVA)
Stable isotopes	$\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values of fish, invertebrate, and algae tissues.	Analysis of Variance (ANOVA)
Water chemistry	Concentration of total nitrogen, total phosphorous, nitrate, nitrite, ammonium	Analysis of Variance (ANOVA)

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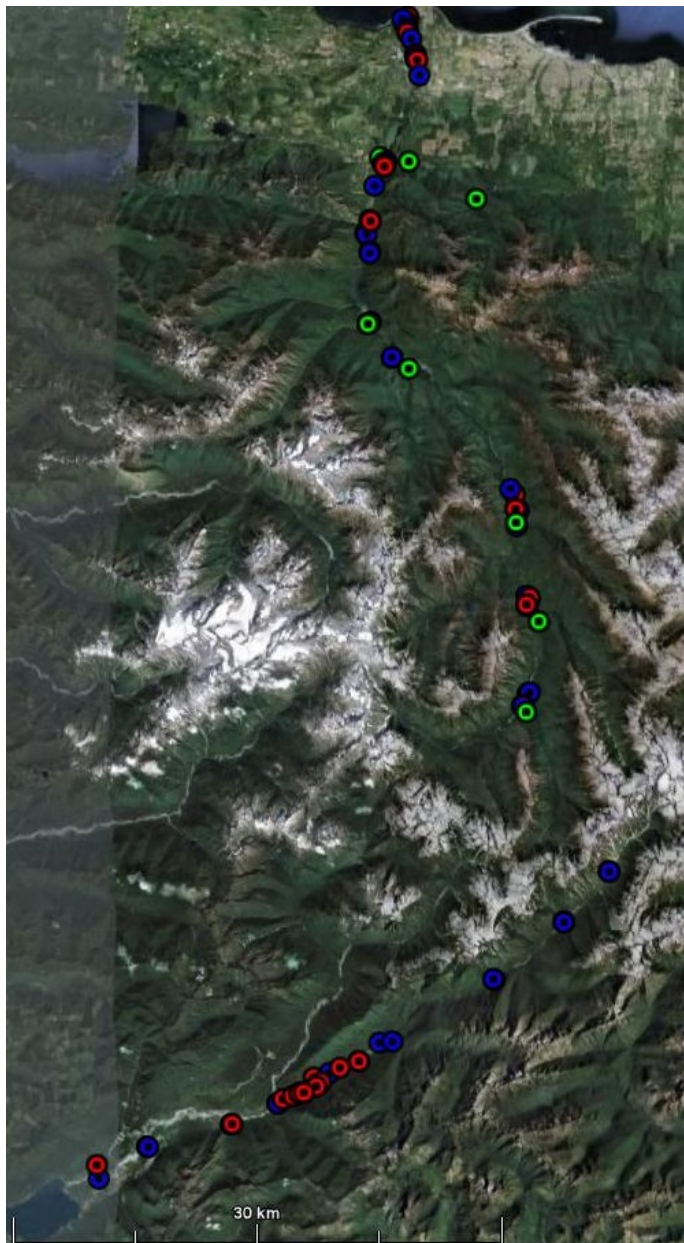
2271 Table C2. Primary and secondary productivity research NOT currently being examined related to
 2272 the Elwha River dam removal.

Category	Metric
Drift patterns of aquatic invertebrates	Drift rates by numerical abundance and biomass Relative abundance of aquatic v. terrestrial food sources
Fish diet composition	Relative abundance of different food sources (e.g., drift vs. benthos, invertebrate vs. fish)
Periphyton taxonomic composition	Taxonomic composition of algal, fungal, and microbial assemblages
Hyporheic processes	Exchange rates of water, nutrients, and invertebrates

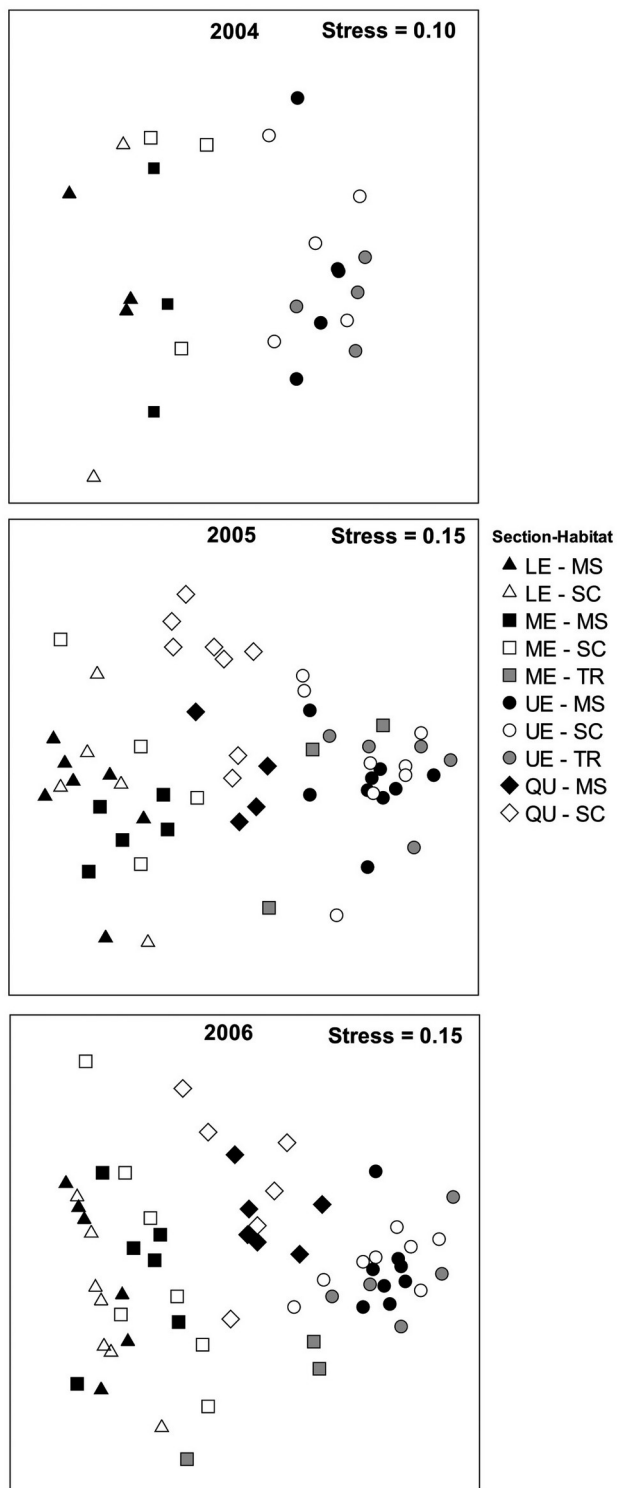
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2274 Figure C1. Locations of Elwha and Quinault Rivers foodweb monitoring locations sampled from
2275 2004-2006 for Morley et al (2006) and Duda et al. (*In Press*). Blue circles indicate mainstem
2276 sites, red circles indicate side channel sites, and green dots indicate tributaries.
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2314 Figure C2. Non-metric multidimensional scaling (nMDS) plots of benthic invertebrate
 2315 community composition data ($\sqrt{}$ transformed) collected from MS (filled), SC (open) and TR
 2316 (shaded) habitats in LE (triangles), ME (squares), UE (circles) and QU (diamonds) (from Morley
 2317 et al. 2008).



2318

2319 Figure C3. Plots of mean (SD) $\delta^{15}\text{N}$ (ordinate) and $\delta^{13}\text{C}$ (abscissa) values for macroalgae,
2320 periphyton, benthic invertebrates, and fish collected above (UE), between (ME), and below (LE)
2321 two dams in the Elwha River during 2005 and 2006 (combined).
2322 (from Duda et al. 2010)
2323

2324
2325

