Nearshore Restoration of the Elwha River Through Removal of the Elwha and Glines Canyon Dams: An Overview

Authors: Shaffer, J. Anne, Crain, Patrick, Winter, Brian, McHenry, Michael L., Lear, Cathy, et al.

Source: Northwest Science, 82(sp1) : 48-58

Published By: Northwest Scientific Association

URL: https://doi.org/10.3955/0029-344X-82.S.I.48

J. Anne Shaffer[1]**,** Washington Department of Fish and Wildlife Habitat Program, 332 E. 5th Street, Port Angeles, Washington 98362

Patrick Crain, **Brian Winter,** Olympic National Park, 600 E. Park Avenue, Port Angeles, Washington 98362

Michael L. McHenry, Lower Elwha Klallam Tribe, 51 Hatchery Road, Port Angeles, Washington 98363

Cathy Lear, Clallam County, 223 E. 4th Street, Port Angeles, Washington 98362

and

Timothy J. Randle, U.S. Bureau of Reclamation, P.O. Box 25007, Mail Code 86-68240, Denver, Colorado, 80225-0007

Nearshore Restoration of the Elwha River Through Removal of the Elwha and Glines Canyon Dams: An Overview

Abstract

Removal of two dams from the Elwha River is a unique restoration opportunity. In place for over 95 years, the dams have contributed to changes in the river, its estuary, and marine areas off shore from the river mouth, largely through reductions in sediment supply and salmon populations. Impending removals of both dams will only restore part of the severely degraded Elwha nearshore, where additional large scale anthropogenic impacts will remain. The effects of lower river levees, marine bluff hardening including significant riprapping of the marine shoreline, among other lesser habitat alterations, will continue beyond dam removal. Understanding the relationship of dam removal to the adjacent nearshore area is critical to the design of additional work necessary for successful ecosystem recovery. We provide an overview of the Elwha nearshore and collaborative efforts underway to understand it, and the role it plays in ecosystem restoration. Dam removal is slated to begin in the next 3 to 5 years making timing of this sorely needed nearshore work critical.

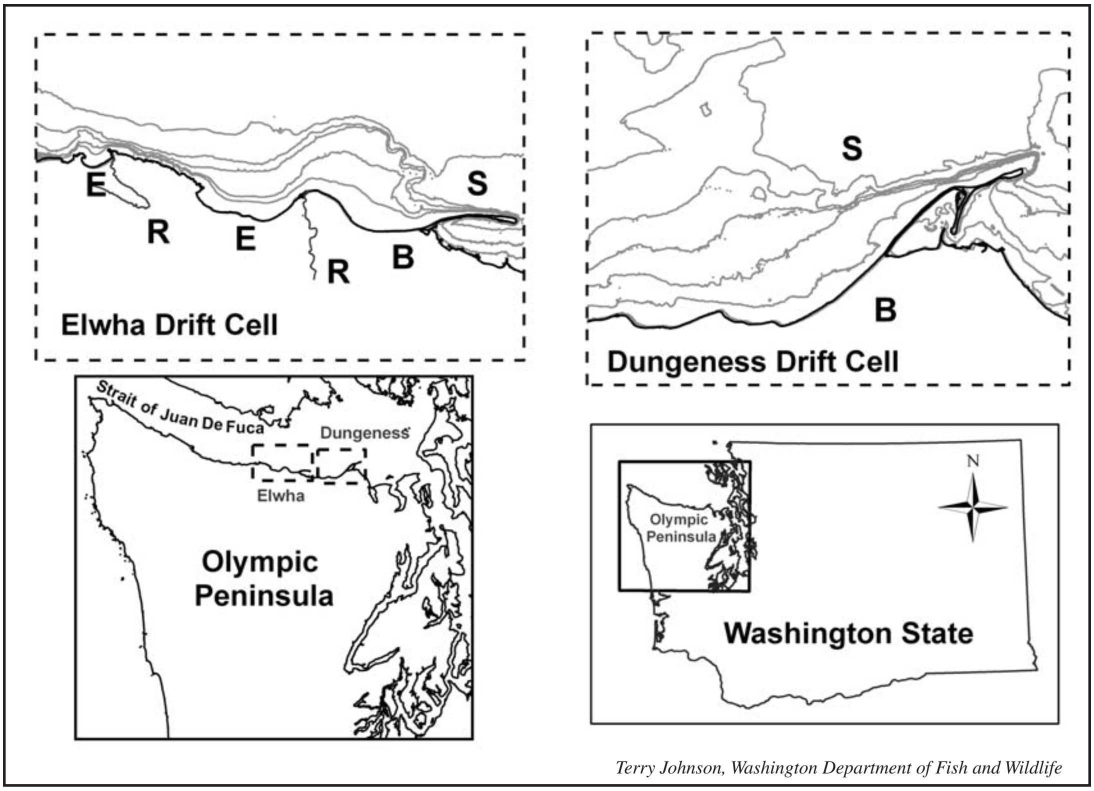
Background

The Elwha River Ecosystem and Fisheries Restoration Act (Elwha Act) calls for, "plans for the full restoration of the Elwha River ecosystem and native anadromous fisheries" (PL102-495, Section 3.c.). This single statement represents one of the strongest calls for restoration of a natural system ever issued by Congress. Since passage of the Elwha Act in 1992, significant effort has been expended on planning restoration of the riverine and upland components of the Elwha River ecosystem (DOI et al. 1994, Wunderlich and Pantealeo 1995, Ward et al. in press) as well as on evaluating expected environmental effects of dam removal (DOI 1995, 1996, 2005), and establishing baseline conditions (Warrick et al. 2008, Duda et al. 2008). However, it is our observation that until recently, very little attention has been directed towards the marine nearshore restoration component, which extends from Freshwater Bay to the tip of Ediz Hook (a large sand spit 3.2 km to the east of the river that forms Port Angeles Harbor; Figure 1), and includes the area of tidal influence to a depth of 30 m Mean Lower Low Water (MLLW) (CCMRC 2004). This lack of activity is perhaps due to an assumption by resource managers that restoration will occur naturally following dam removal (Seavey and Ging 1995), and that no other action is needed. Alternatively, the marine nearshore area is outside Olympic National Park, falling within a multitude of private, city, state, and Tribal jurisdictions, imposing management complexities that require significant coordination to implement successful restoration efforts. Regardless, if the restoration goal laid out by Congress is to be achieved, the marine nearshore component of the Elwha River ecosystem must also be included.

The construction of the Elwha Dam in the early 1900s, and the Glines Canyon Dam a few years later, disrupted the structure and habitat maintaining processes of the Elwha nearshore, primarily through the disruption of sediment and wood delivery. Prior to construction of the Elwha Dam the Elwha River delivered approximately 160,000 m^3yr^{-1} of fine and course sediment to the mouth of the Elwha River (Randle et al. 1996). This

---

[1] Author to whom correspondence should be addressed.
E-mail: shaffjas@dfw.wa.gov



Terry Johnson, Washington Department of Fish and Wildlife

Figure 1. Olympic Peninsula and Elwha and Dungeness drift cells. Geomorphic features, from west to east: E = Embayments (Crescent Bay and Freshwater Bay); F = Feeder bluffs (Elwha Bluffs, Dungeness Bluffs); R = River (Pysht, Twins, Salt Creek, and Elwha River);S = Spits (Ediz Hook and Dungeness Spit).

material was then generally transported to the east through wind and wave action, replenishing beach substrate and contributing to the maintenance of Ediz Hook (Schwartz 1972, 1994). As a result of dam construction, over 15 million m^3 of sediment that would have been delivered to the nearshore is instead currently trapped behind the two dams (Randle et al. 2004). This sediment starvation is believed to have contributed to the coarsening of the Elwha nearshore as well as incision in the lower river. Wood recruitment from the river, a critical component to nearshore marine processes, has also been disrupted. These changes in physical habitat are theorized to have contributed to shifts in the biological habitat and function of the Elwha nearshore.

The Elwha River dams are not the only factor disrupting the the structure (e.g., mixed particle size beach) and function (e.g., habitat for marine benthic invertebrates and shell fish) of the Elwha nearshore environment. Several other specific anthropogenic factors including shoreline revetments and estuarine diking work in concert with one another to limit recruitment of sediment, alter wave action, disrupt littoral drift, and isolate estuarine habitat (Haring 1999). A 3300 m long bulkhead, installed in the late 1950s and extending from the base of Ediz Hook west towards the Elwha River, protects the City of Port Angeles industrial water pipeline and, with a 200 m extension in 2007, the municipal land fill. This bulkhead has prevented erosion of feeder bluffs that are estimated to have formerly provided over 70% of beach material to Ediz Hook (USCOE 1971, Galster 1978).

While we believe that dam removal will play a critical role in restoration of nearshore habitat, habitat forming processes, and ecosystem function—a priority for nearshore and watershed management in Washington State (Fresh et al. 2004)—we anticipate that the full benefits of dam removal will not be realized in the nearshore environment without additional restoration efforts. This paper provides an overview of the Elwha nearshore marine environment, and describes our approach for identifying additional actions to restore nearshore function.

The Elwha Nearshore Marine Environment

Nearshore habitat function of the Elwha nearshore for fish and invertebrate communities is defined by a combination of physical and biological processes and components, and may vary significantly temporally and within and between habitats (Miller et al. 1980, Simenstad et al.1988, Carter 1999, Carter and VanBaircom 1998, VanBlaircom and Chambers 2003). The Elwha River meets the Strait of Juan de Fuca approximately 10 km west of Port Angeles (Figure 1). Within the Strait of Juan de Fuca, we define the Elwha nearshore as the approximately 21 km of shoreline that extends from the west end of Freshwater Bay east to the tip of Ediz Hook (CCMRC 2004). This area encompasses the primary marine area of littoral drift (USACOE 1971). The Elwha nearshore environment is further delineated by the physical features of tidal influence and light limitation and extends from the area of tidal influence and tree line to 30 m below MLLW (CCMRC 2004, Shaffer et al. 2005).

The Strait of Juan de Fuca connects inland waters of Puget Sound with the Pacific Ocean. Over 80% of the water from Puget Sound and the Strait of Georgia (Canada) flows through this relatively narrow passage lying between Vancouver Island and the Olympic Peninsula (Mackas and Harrison 1997). It is a unique water body that, in addition to providing critical rearing habitat for forage fish, juvenile salmonids, and other marine life, also acts as an important conduit for species migrating to and from inland marine and fresh waters of Puget Sound and British Columbia (Palsson et al. 2004, Sweeting et al. 2004, Averill et al. 2005). The direction of net water movement in the Strait of Juan de Fuca depends on depth. Cold, deep oceanic water tends to move to the east while fresher, warmer surface water tends to move to the west (Strickland 1983, Mackas and Harrision 1997).

The shoreline of the Strait of Juan de Fuca, including the Elwha nearshore, is heterogeneous. Sand, gravel, and cobble beaches are found along the shoreline. High bluffs of glacial deposits act as feeder bluffs, which provide material to the nearshore that is important in sustaining large spits (e.g., Ediz Hook, Dungeness Spit). Sheltered coves, small estuaries, and erosion resistant marine sediment are also present (Todd et al. 2006). The coastline is defined by glacial events, the most recent of which was the last advance of the Cordilleran ice sheet approximately 16,000 years ago (Downing, 1983).

In the Elwha nearshore area, nearly all of the various beach types are represented. The western end of Freshwater Bay is characterized by sandstone features, with the shoreline dropping away rapidly to deep water. Central Freshwater Bay is characterized by gently sloping gravel and cobble beaches. This habitat slowly transitions to a sandier substrate approaching the mouth of the Elwha River. To the east of the Elwha River higher energy beaches are found. These are dominated by large cobble and feeder bluffs that extend east to, and historically provide the sediment that formed, Ediz Hook. Approximately 3300 m of these feeder bluffs are disconnected from the shoreline by rock and sheet pile bulkhead that runs from the mouth of Dry Creek to the tip of Ediz Hook.

The Elwha estuary at the mouth of the Elwha River, located at the eastern entrance of Freshwater Bay, is a critical component of the Elwha nearshore. Historically, this feature included nearly 0.40 km^2 of estuarine wetland. Currently, the estuary is severely limited due to the presence of the dams, mechanical straightening of the river, and construction of floodplain levees. Only approximately 0.12 km^2 of intact estuarine wetland habitat remain. This is important, as estuarine habitat in the Strait of Juan de Fuca is generally limited (Todd et al. 2006).

Physical Processes that Define the Elwha Nearshore

A number of physical processes define the Elwha nearshore. The Strait of Juan de Fuca, including the Elwha nearshore, is a wind-dominated system, with currents changing dramatically within hours in response to both regional and larger-scale oceanic winds (Strickland 1983, Hickey 1996, Hickey and Bonas 2003). Wave action resulting from strong winds creates high energy type beaches characterized by coarse substrates.

Strong seasonal storms contribute pulses of both freshwater and sediment to the Strait of Juan de

Fuca. These pulses form large lenses of very low salinity and very high turbidity water within the nearshore zone along the majority of the shoreline of the Strait of Juan de Fuca. These lenses appear to occur primarily during winter and spring months (Anne Shaffer, WDFW, personal observation). Due to deep oceanic water, strong wind, and current mixing action, as well as seasonal contributions of riverine nutrients, the water of the main basin of the Strait of Juan de Fuca is well-mixed, cold, and nutrient-rich throughout the year (Mackas and Harrison 1997). This is in direct contrast to shallow, enclosed embayments of the Strait of Juan de Fuca, which may be seasonally stratified and in some instances nutrient-limited (Mackas and Harrison 1997, Jan Newton, University of Washington, personal communication).

Biota

Vegetated habitats are dominant in intertidal and shallow subtidal portions of the Strait of Juan de Fuca nearshore, and are found along at least 60% of the shoreline. Kelp forests, which require hard substrate for anchoring of holdfasts and are found along 40% of the Strait of Juan de Fuca shoreline, represent the most prevalent nearshore plant community. These extensive beds are comprised of three dominant species of kelp (*Macrocystis integrifolia* or giant kelp, *Nereocystis luetkeana* or bull kelp, and *Pterygophora californica,* an understory kelp), which have dramatically different life histories. *Zostera marina* (eelgrass) is a vascular plant that requires a sand gravel substrate and occupies at least 20% of the Strait of Juan de Fuca shoreline (Thom and Hallum 1990, Shaffer 2000, VanWagenen, 1998). In total, kelp beds of the Strait of Juan de Fuca, which are found along at least 40% of the shore, make up the majority (78%) of Washington's coastal kelp resources (Thom and Hallum 1990, Vanwagenen1996, 1998).

Fish assemblages of the Elwha nearshore include three federally- and/or state-listed salmon (Puget Sound Chinook, *Oncorhynchus tshawytscha*, Strait of Juan de Fuca/Hood Canal summer chum, *O. keta*, and bull trout, *Salvelinus confluentus*), as well as sockeye (*O. nerka*), pink (*O. gorbuscha*) and cutthroat (*O. clarki clarki*.), many rockfish species (including copper, *Sebastes caurinus*, quillback, *S. maliger*, and black, *S. melanops* rockfish) and bottom fish, including halibut (*Hippoglosus stenolepis*). Forage fish, including eulachon (*Thaleichthys pacificus*), surf smelt (*Hypomesus pretiosus*), sand lance (*Ammodytes hexapterus*), and herring (*Clupea harengus pallasi*), use the Elwha shorelines for spawning, feeding, and migration. Their use, as well as that by juvenile salmon, may be highly variable geographically as well as from year to year, and depends on physical and biological features such as rocky outcrops, kelp forests, and sandy substrates (Shaffer and Schilke unpublished data, Shaffer et al. 2003, Shaffer 2004, Shaffer et al. 2007).

Shellfish species found in the Elwha nearshore include numerous species of crab, shrimp, geoduck (*Panopea generosa*), abalone (*Haliotis* spp.), scallops (*Hinnites* spp.), native and Pacific oysters (*Concophelia lurida* and *Crassostrea gigas*) as well as urchin (*Strongulocentrotis* spp.) and a variety of sea cucumber. Elwha nearshore and marine wildlife assemblages include alcids (marbled murrelets, *Brachyramphus marmoratus*, tufted puffins, *Lunda cirrhata*, rhinoceros auklets *Cerorhinca monocerata* and others), Dall's porpoise (*Phocoennoides dalli*), Harbor porpoise (*Phocoena phocoena*), Orca (*Orcinus orca*) and Gray whales (*Eschrichtium robustus*) (Angell and Balcomb 1982)

Nearshore vegetated habitats within the Elwha, which are largely dictated by available substrate type, include kelp beds, eelgrass beds, drift algae, and rocky/cobble shorelines with Laminarian cover (Norris et al. 2007, Warrick et al. 2008). Seavey and Ging (1995) identified a total of 40 aquatic plant species in the Elwha nearshore area.

Factors Limiting Elwha Nearshore Ecosystem Function

Disruption of sediment sources and transport has had a significant effect on the shoreline and river estuary that collectively make up the Elwha nearshore. A 3000 m bulkhead was installed in the late 1950s along the shoreline east of the river mouth to the base of Ediz Hook, to protect the City of Port Angeles industrial water line. This bulkhead has prevented erosion of a critical feeder bluff that is estimated to have formerly provided over 70% of beach material to the Elwha littoral system (USCOE 1971, Galster 1978). Another 300 m section of shoreline has just been armored by the City of Port Angeles. The Elwha and Glines Canyon dams have further limited sediment supply to the nearshore, resulting in substantial loss of riverine sediment to the Elwha nearshore for almost a century. Combined, the dams and shoreline armoring have resulted in a nearly complete loss of sediment-related habitat as well as aggravating significant long-term erosion of nearshore sediment from the mouth of the river east to Port Angeles Harbor (USCOE 1971, Schwartz 1972, Downing 1983, Harring 1999). The significance of the almost complete sediment starvation of the Elwha drift cell is clearly illustrated when one compares the Elwha drift cells to other drift cells in the region. For example, there is a distinct contrast between the shorelines of Ediz Hook, with armored feeder bluffs and accelerated chronic erosion, to those of Dungeness Spit, a five mile long spit approximately 20 km to the east of the Elwha drift cell. The Dungeness drift cell has intact feeder bluffs and sediment transport. Ediz Hook shoreline is coarse, steep, and requires continual shoreline augmentation. Dungeness Spit, on the other hand, has broad flat beaches that are self maintained. This contrast between what were once very similar features is a result of the disruption of sediment processes along the Elwha nearshore. The resulting sediment starvation is theorized to have caused a reduction in eelgrass and expansion of kelp beds in the Elwha drift cell. It has also caused shoreline erosion patterns to change, steepening and coarsening intertidal beaches of the Elwha drift cell. This in turn may impact Elwha beach ability to support certain hard shell clams, Dungeness Crab (*Cancer magister)*, and intertidal forage fish spawning (Seavey and Ging 1995).

Sediment limitation has also impacted lower river nearshore habitat. Unconstrained, low gradient channel reaches in the lower Elwha River historically contained extensive side channels (Pess et al. 2008) and estuarine slack water habitats with suitable substrate for critical fish use including eulachon spawning. Truncation of sediment transport to the lower river, along with channelization, and the systematic removal of large woody debris (LWD), has caused channel incision and an increase in bed substrate size (Pohl 2004). Nearshore effects of this disruption likely include a significant reduction in side channel habitat and a reduction in suitable eulachon spawning habitat (Shaffer et al. 2007).

Dikes in the lower Elwha River also have had a significant effect on the nearshore, including altering and restricting use of over 0.30 km^2 of tidal influenced estuary and sediment delivery and fate in the nearshore. Fish use in the unconstrained eastern and western portion of the river mouth estuary is extremely high in species numbers, richness, and includes some of the highest abundances of juvenile federally listed salmon species in the central and western Strait (Shaffer and Schilke WDFW unpublished data, Matt Beirne Lower Elwha Klallam Tribe unpublished data). During six weeks of beach seining in the west estuary using PSAT protocols, Shaffer and Shilke (WDFW unpublished data) documented that little to no salmonid use occurs in the majority of the constrained western Elwha River mouth estuary due to large dike constructed in the 1950s that completely blocks salmonid access (Table 1; Shaffer and Schilke WDFW unpublished data).

Elwha Nearshore Restoration and Ecosystem Recovery Approach

Elwha dam removals will result in a restoration of sediment processes to the Elwha watershed, including the nearshore. Dam removal is expected to deliver approximately 1.8 to 2.4 million m^3 of coarse (sand and gravel) sediment and (4 to 5 million m^3) of fine (sand/silt) sediment from the reservoirs to the nearshore area within five years of project completion (BOR 1996, Randle et al. 2004). After this initial pulse, delivery of sediment is anticipated to equal pre-dam annual delivery rates of approximately 80,000 m^{3}yr^{-1} of coarse and 80,000 m^{3}yr^{-1} of fine sediment (BOR 1996).

Although there are varied opinions on the details of this restoration, it is generally anticipated

TABLE 1. Fish use (% composition) of two sites in the western Elwha River estuary from weekly beach seining, March–June 2007 (Shaffer and Schilke, unpublished data).

Elwha Estuary Site	Chinook Salmon	Coho Salmon	Chum Salmon	Smelt	3-spine Stickleback	Starry Flounder	Staghorn Sculpin	Cottids
Connected	55	16	7	2	4	3	8	4
Diked	0	0	0	0	100	0	0	0

that restored sediment transport may occur in two distinct phases (Stolnack and Naiman 2005). In the first phase, total sediment volumes released are estimated to be 6 to 7 million m^3. The majority of this sediment delivery phase is anticipated to occur within three to five years after dam removal (Randle et al. 2004). The second phase occurs when the natural sediment supply from the upstream watershed is restored to the lower Elwha River (Randle et al. 2004). Delivery of sediment is anticipated to equal pre-dam annual delivery rates totaling approximately 160,000 m^3yr^{-1} (BOR 1996).

Restoration of natural riverine sediment processes following dam removal will only partially restore the suite of physical and ecological processes of the Elwha nearshore. The distribution and duration of residence of riverine sediment delivered to the nearshore is largely unknown. The role of remaining nearshore alterations in disrupting sediment processes (specifically the disruption of sediment delivery to shorelines and continued starving of bluff sediment to the nearshore) is at this time also unknown. Given the historic importance of feeder bluffs to the Elwha system it is clear that restoration of sediment processes will be far from complete and that sediment delivery along the Elwha drift cell will still be far short of pre-dam rates.

Restoration of sediment and hydrologic processes in the lower river, including the estuary will also be incomplete. Dikes along the east and west river mouth will preclude restoration of sediment delivery to the nearshore. It will also continue to disrupt hydrologic connectivity between the river and off-channel habitats, especially to the estuarine complex west of the river mouth. This will continue to effect fish utilization of the Elwha River estuary. The dikes in the lower river and shoreline alterations, such as bluff armoring, will therefore continue to have a significant impact on the natural physical and biological processes of the Elwha nearshore.

Additional restoration actions will be necessary to fully realize the nearshore restoration potential associated with the upcoming dam removals. Defining the technical details of restoration options and prioritizing which actions to take first is clearly complicated. Having a detailed understanding of the Elwha nearshore is critical to defining the next restoration priorities and actions. A group of nearshore scientists and managers convened in 2004 by the citizen based Clallam Marine Resource Committee (MRC), Clallam County, Elwha Tribe, state agencies, and Olympic National Park to define the technical, management, and educational needs for restoring the central Strait of Juan de Fuca and the Elwha nearshore (CCMRC 2004). The resulting Elwha Nearshore Consortium has subsequently been addressing these identified needs. Highlights of the intensive work over the last two years are summarized in Table 2. Intriguing findings from these efforts are emerging, including: Norris et al. (2007) documented remnant but persistent eelgrass beds off of Ediz Hook, and large numbers of juvenile forage fish associated with understory kelp beds. Helen Barry and colleges at the Washington Department of Natural Resources, have described historic and current kelp bed composition and distribution in the Elwha nearshore. Beirne (Lower Elwha Klallam Tribe unpublished data) and Shaffer and Schilke (WDFW, Peninsula College, and Western Washington University unpublished data), have documented heavy forage fish and salmonid use of the Elwha estuary, and strong seasonal variation in nearshore habitat use by salmonids and forage fish. They have also documented, for the first time, federally listed Elwha stocks of Puget Sound Chinook using the nearshore of the western Strait of Juan de Fuca, and surf smelt spawning along beaches of Freshwater Bay, which is within in the Elwha drift cell, and along active feeder bluffs of the adjacent Dungeness drift cell. Andrea Ogston's observations have documented the present low quantity of fine sediment in suspension during summer, high river discharge conditions. Strong tidal currents on the Elwha delta result in bed stresses that are capable of resuspending recently deposited fine-grained sediment at spring tides. The seabed mapping, in combination with the USGS efforts, provides detailed seabed bathymetry and characterization of the Elwha delta to water depths of ~100 m. Warrick et al. (2008), catalog kelp distribution in the vicinity of the Elwha River mouth. These studies provide a baseline for understanding current and historic habitat distribution within the Elwha nearshore, the fine-and course sediment dispersal in the marine system, including high-concentration sediment flows, at present and in the future (Table 2).

While individual results are important, in order to truly define the restoration response of

TABLE 2. Current activities (yrs of project) of Elwha Nearshore Consortium (ENC) members.

Name	Affiliation	Focus	Timeline
Anne Se^ccbo	T ACT	±L sbo^ii BK@@l l oafk^qfl k ±Cfpe r pb) e^_fq^qcr k`qfl k	±L kdl fkd ±Rkabot ^v %&
@^qev I b^o	@l^ii^j @l r kqv	±BK@^ka `fqfwbk `l l oafk^qfl k ±T bpqibs v ª pe m^pp^db ±T bpqbpqr ^ov obpqd o^qfl k	±L kdl fkd ±Rkabot ^v %- & ±Rkabot ^v
J ^qq ? bfokb	I BHQ	±BK@^ka Qof_^i @l l oafk^qfl k ±B`l pvpqbj ^ppbppj bkq ^ka cr k`qfl k l c east estuary	±L kdl fkd ±Rkabot ^v %&
Ol _ Bil qpl k	I BHQ	±Qof_^i Bit e^ mol gb`qj ^k^dbo) bpqr ^ov obpqd o^qfl k	±L kdl fkd
? fii B^qd k) Dwight Barry	Mbkfkpr i^ @l iibdb	±Bit e^ Obpb^o`e @l kpl oqfr j %BO@& Coordination, Research Experiences for Undergraduates (REU) student coordination	±L kdl fkd
E bibk ? boov	T > AKO	±Hbime^_fq^qj ^mmfkd	±L kdl fkd
> j v Ao^r q	RPDP	±@e^kkbi j l omel il dv) il t bo Bit e^ Ofsbo	±Rkabot ^v %&
Hr oq Cobpe	KL> >	±Cfpe r pb	±Rkabot ^v %&
A^s fa Cobba	T PR ? b^`et ^q`ebop	±Sl ir kqbbo `l l oafk^qfl k	±L kdl fkd
Dr v Dbicbk_^r j	RPDP	±J b^pr ofkd ^ka j l abifkd `l ^pq^i t ^sbp hydrodynamics and sediment transport	±L kdl fkd
Q^o^kd He^kd^l kh^o	? ^qbiib MKKI	±E vadl avk^j f` ^ka qp^kpml oqj l abi l c Puget Sound including Elwha nearshore	±L kdl fkd
O^vj l ka J l pbp	I BHQ	±I l t bo ofsbo ^ka bpqr ^ov ª pe r pb	±Rkabot ^v %&
Gfj Kl oofp	J bkwfbp Mol gb`q	±Bbido^pp J ^mmfkd	±@l j mibqb
@er `h Kfqqpl r bo	RT	±Cfkb pbafj bkqj ^mmfkd	±Rkabot ^v %&
> kaob^ L dpqd k	RT	±Cfkb pbafj bkqj ^mmfkd	±Rkabot ^v %&
A^s b M^ohp	T > AKO	±@l ^pq^i mol `bppbp ±? b^`e j ^mmfkd	±L kdl fkd ±L kdl fkd
@e ofp Mbbov	R l c F	±T b_ m^db abs bil mj bkq	±@l j mibqb
Qfj O^kaib	? L O	±Ofsbo evao^r if`p ±Pbafj bkq qp^kpml oq ±Dbl j l omef` `e^kdb	±Rkabot ^v %1& ±Rkabot ^v %- & ±Rkabot ^v %- &
Al k O^r qe^r p	T ACT	±Pebiiª pe e^_fq^qj ^mmfkd ±Cil o^ ^ka c^r k^ `l j j r kfqv pqor `qr ob ±Pebiiª pe ml mr i^qfl k `e^kdb	±? ^pbifkb a^q^ %0& ±? ^pbifkb a^q^ %0& ±? ^pbifkb a^q^ %0&
M^q Pe^col qe	RPDP	±Bpqr ^ofkb ^ka ofm^of^k s bdbq^qfl k diversity and dynamics	±Rkabot ^v %&
Gbccobb Pqbt ^oq	T > ALB	±Pel obifkb j ^k^dbj bkq ^ka mi^kkfkd	±L kdl fkd
Pqbs b Ql aa	M fkq Kl M fkq Treaty Council	±E fpql of` e^_fq^qj ^mmfkd	±@l j mibqb
I ^oov T ^oa	I l t bo Bit e^ Klallam Tribe	±Cfpe Rpb	±Rkabot ^v %&
Gbcc T ^oa) Patty Morris, Mike Doherty	? ^qbiib MKKI NOPRC&D	±J l abifkd) K> P> `l l oafk^qfl k	±Rkabot ^v %&
Gl ek T ^oof`h	RPDP	±Kb^opel ob _^qevj bqov ±? b^`e `l j ml pfqfl k ^ka mol ª ifkd	±@l j mibqb ±L kdl fkd
A^k^ T l l aor cc	? ^qbiib MKKI	±E vmbopmb`qp^i fj ^dbov `l iib`qfl k ±Kb^opel ob e^_fq^qj ^mmfkd	±L kdl fkd ±L kdl fkd
Ol _ Vl r kd	T bpqbok @^ol ifk^ University	±@l ^pq^i mol `bppbp	±Rkabot ^v

the Elwha nearshore it is going to be necessary to bring these physical, biological, and ecological elements together. Shaffer et al. 2005 identified four key steps to defining, and optimizing, Elwha nearshore ecosystem response, with an emphasis on fish use:

1) Define the geographic and temporal fate of the sediment once in the nearshore;
2) Define historic habitat conditions and key fish and vegetation habitat resource distribution;
3) Define current habitat distribution and resource use, and;
4) Model future conditions based on integrating these three parameters to define areas of greatest additional restoration need and potential.

Individual components of these steps are being addressed in varying degrees as described above. Bringing these individual elements together to predict future habitat conditions based on historic, current, and future sediment transport, habitat condition, and fish use is our next priority. Sediment processes are being defined by USGS, University of Washington, and the Lower Elwha Klallam Tribe. Historic habitat conditions have been identified to some degree by Todd et al. Current habitat distribution and use is being defined by Barry et al. and Norris et al. Current resource use is being defined by Beirne et al., Shaffer et al., and Fresh et al. (Table 2).

Quantitative modeling combining physical processes, habitat distribution, and fish use will be the tool to provide a predictive eye to nearshore restoration priorities. These models will need to address uncertainty and propagation of error. Modeling is a critical component for defining restoration priorities in nearshore Washington (Fresh 2006, Simenstad et al. 2006). Restoration work that has included extensive modeling efforts in the Skagit system has revealed important linkages between salmonid use in the nearshore and restoration priorities there (Beamer et al. 2003, Beamer et al. 2005). Modeling that links biological and sediment processes in the nearshore have also been conducted in other areas (Uncles 2003). The unique nature of the Elwha nearshore including its unique limiting factors, large size, remote location, and upcoming restoration event make it appropriate for the development of specific modeling tools. Modeling will, however, be dependent on adequate data; given the variable nature of the Elwha nearshore, this will require intensive, multi-year data sets.

How then, does one proceed with predicting, via modeling, the priorities to optimize the Elwha nearshore restoration response to dam removals? This is just beginning to unfold. A central component of this prediction process will be defining: 1) The degree of restoration action that still needs to occur to achieve nearshore ecosystem restoration (for example, restoration of shoreline sediment processes); and 2) the role remaining nearshore alterations play in habitat function post dam removal. One challenge before us is predicting post dam removal habitat use. Post dam removal monitoring will be too late to define pre-dam removal actions that might optimize the restoration event. Given the time-sensitive nature of our work, we suggest defining current habitat process and function of the Elwha nearshore relative to intact comparative geomorphic habitats outside the Elwha drift cell as a tool for helping to understand how the Elwha drift cell would function if fully intact. For example, the Dungeness drift cell is an appropriate comparative area to the Elwha drift cell. It has many of the same geomorphic habitat types and the same dominant physical processes as the Elwha, but is not influenced by in-river dams and feeder bluff armoring. There are also a number of lower rivers, estuaries, and embayments of the central and western Strait that are similar to those in the Elwha nearshore but do not have the limiting features of the Elwha nearshore (Table 3). Simultaneously defining the variability of nearshore form and functions both in the Elwha and comparative areas will give us insight into both how the Elwha is functioning differently now, and give us a target for how the Elwha nearshore might function if fully restored. This information may then be combined with sediment mapping efforts to model what we expect Elwha nearshore habitats to look like following dam removal. Combining these pieces we can then tease out what additional actions might be necessary and appropriate to achieve the highest ecosystem restoration possible. Once we have the list of habitat restoration actions we can define the highest priority of these additional restoration actions. Actions that must occur prior to dam removal will receive the highest priority. Any on-the-ground restoration actions that involve private property will require participation and agreement

TABLE 3. Comparative geomorphic sites arranged by habitat type. Bold text indicates sites within the Elwha drift cell.

Site	Embayments	Spit	Lower River-Pocket Estuary	Feeder Bluff
West Twins R. Estuary			X	
Pysht Lower R. Estuary			X	
Salt Cr. Estuary			X	
Elwha R. Estuary			X	
Twins Shoreline	X			
Pysht Shoreline	X			
Crescent Bay	X			
Freshwater Bay Shoreline	X			
Elwha Bluffs				X
Dungeness Bluffs				X
Ediz Hook		X		
Dungeness Spit		X		

by private citizens. This additional coordination with land owners adds an additional time element to our work, and so makes restoration work in the nearshore that much more time sensitive.

Clearly, collaboration and good will between scientists, managers, the tribe, private citizens and educational institutions is necessary for us to succeed in accurately defining nearshore restoration response and implementing nearshore restoration actions of the Elwha nearshore. We have been very successful so far. With dam removal slated to begin in the next 3 to 5 years, time is of the essence.

Conclusion

The Elwha nearshore is a complex and diverse component of the Elwha ecosystem that has been significantly disrupted by a suite of habitat alterations, including lower river alterations and significant sediment starvation due to riverine dams and shoreline armoring. Removal of two dams on the Elwha River is expected to deliver a large quantity of coarse and fine sediment to the Elwha nearshore within five years of project completion. Additionally, dam removal will restore the natural delivery of riverine sediment. However, it is expected that dam removal alone will only partially restore function of the Elwha nearshore in the Central Strait of Juan de Fuca. Understanding the relationship between dam removal and the adjacent nearshore area is critical to the design of additional work necessary for successful recovery of the sediment starved central Strait of Juan de Fuca and the ecosystem it supports. Dam removal is slated to begin in the next 3 to 5 years, making timing of this sorely needed nearshore work critical.

Acknowledgements

The Elwha Nearshore Consortium members Drs. Andrea Ogston, UW, and Jon Warrick, USGS, Msrs. Dave Parks, WDNR, Don Rothaus, WDFW, and Matt Beirne, LEKT, provided input on their respective work. Mr. Jeff Duda, USGS, as the special edition journal editor, coordinated manuscript review. Mr. Terry Johnson, WDFW, provided much appreciated GIS expertise. Two anonymous reviewers provided helpful suggestions for manuscript revision.

Literature Cited

Angell, T. and K. Balcomb. 1982. Marine birds and mammals of Puget Sound. Washington Sea Grant, Seattle, WA.

Averill, D., D. Myers, and B. Graeber. 2005. Puget Sound nearshore and marine ecosystems: processes, landscapes, habitats. *In* S. Redman, D. Myers, and D. Averill (editors), Regional Nearshore and Marine Aspects of Salmon Recovery in Puget Sound. Delivered to Shared Strategy for Puget Sound for inclusion in their regional salmon recovery plan. Available online at http://www.psat.wa.gov/Programs/salmon_recovery/environments.htm (viewed on 7 Feb 2008).

Beamer, E., R. Henderson, A. McBride and K. W. Wolf. 2003. The importance of non-natal pocket estuaries in Skagit Bay to wild Chinook salmon: an emerging priority for restoration. Skagit River System Cooperative, Research Department, La Connor, WA.

Beamer, E., A. McBride, C. Greene, R. Henderson, G. Hood, K. Wolf, K. Larsen, C. Rice, and K. L. Fresh. 2005. Delta and nearshore restoration for the recovery of wild Skagit River Chinook salmon: linking estuary restoration to wild Chinook salmon populations. Supplement to Skagit Chinook Recovery Plan. Skagit River System Cooperative, La Conner, WA.

Bureau of Reclamation (BOR). 1996. Sediment analysis and modeling of the river erosion alternative. Elwha Technical Series, PN-95-9. U.S. Department of the Interior, Bureau of Reclamation, Pacific Northwest Region, Boise, ID.

Carter, S. K. 1999. Ecosystem effects of sea otter predation and commercial sea urchin harvest on nearshore benthic habitats in Northern Washington. M.S. Thesis, University of Washington, Seattle.

Carter S. K. and G. R. VanBlaircom. 1998. A survey of nearshore benthic habitats of the Strait of Juan de Fuca from Kydaka Point to Port Angeles. Final report to the WDFW. University of Washington, School of Fisheries, Seattle.

Clallam County Marine Resources Committee (CCMRC). 2004. Technical workshop on nearshore restoration in the central Strait of Juan de Fuca. Prepared for CCMRC by Triangle Associates, Seattle, WA. http://www.clallammrc.org/CCMRC/allframes.html

Department of the Interior (DOI), Department of Commerce, and the Lower Elwha S'Klallam Tribe. 1994. The Elwha Report—Restoration of the Elwha River ecosystem and native anadromous fisheries. A report to Congress submitted pursuant to Public Law 102-495. U.S. Government Printing Office: 1994-590-269.

Department of the Interior (DOI). 1995. Elwha River ecosystem restoration, final environmental impact statement. NPS D-253A. Department of the Interior, National Park Service, Olympic National Park, Port Angeles, WA.

Department of the Interior (DOI). 1996. Elwha River Ecosystem Restoration Implementation, Final Environmental Impact Statement. NPS D-271A. Department of the Interior, National Park Service, Olympic National Park, Port Angeles, WA.

Department of the Interior (DOI). 2005. Elwha River Ecosystem Restoration Implementation, Final Supplement to the Final Environmental Impact Statement. NPS D-377A. Department of the Interior, National Park Service, Olympic National Park, Port Angeles, WA.

Downing, J. 1983. The coast of Puget Sound: Its processes and development. Washington Sea Grant, University of Washington Press, Seattle.

Duda, J. J., J. E. Frelich, and E. G. Schreiner. 2008. Baseline studies in the Elwha River ecosystem prior to dam removal: introduction to the special issue. Northwest Science 82 (Special Issue):1-12.

Fresh, K. , C. Simenstad, J. Brennan, M. Dethier, G. Gelfenbaum, F. Goetz, M. Logsdon, D. Myers, T. Mumford, J. Newton, H. Shipman, and C. Tanner. 2004. Guidance for protection and restoration of the nearshore ecosystems of Puget Sound. Puget Sound Nearshore Partnership Report No. 2004-03. Published by Washington Sea Grant Program, University of Washington, Seattle.

Fresh, K. L. 2006. Juvenile Pacific salmon and the nearshore ecosystem of Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-06. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, WA.

Galster, R. W. 1978. Ediz Hook—A Case History of Coastal Erosion and Mitigation. Engineering Geology of Washington Volume 2. Washington Division of Geology and Earth Resources Bulletin 78.

Haring, D. 1999. Salmon and steelhead habitat limiting factors, WRIA 18. Washington Conservation Commission Final Report, Olympia, WA.

Hickey, B. 1996. Physical Oceanography of the Olympic Coast. *In* Olympic Coast Marine Research Workshop Proceedings. Occasional Paper OCNMS 96001.Olympic Coast National Marine Sanctuary. Port Angeles, WA.

Hickey, B. M. and N. S. Banas. 2003. Oceanography of the U.S. Pacific Northwest coastal ocean and estuaries with application to coastal ecology. Estuaries 26:1010-1031.

Mackas, D. L. and P. J. Harrison. 1997. Nitrogenous nutrient sources and sinks in the Juan de Fuca/Strait of Georgia/Puget Sound Estuarine System: Assessing Potential for Eutrophication. Estuarine, Coastal, and Shelf Science 44:1-21.

Miller, B. S., C. A. Simenstad, J. N. Cross, K. L Fresh, and S. N. Steinfort. 1980. Nearshore fish and macroinvertebrate assemblages along the Strait of Juan de Fuca including food habits of the common nearshore fish. Final report of three years sampling 1976-1979. EPA No. D6-E693-EN. Office of Environmental Engineering and Technology Office of Research and Development, US EPA, Washington, DC.

Norris, J, I. Ward**,** A. Shaffer and C. Lear. 2007. Eelgrass mapping of the Elwha Nearshore. *In* Proceedings of the 2007 Georgia Basin Puget Sound Research Conference, Puget Sound Partnership, available online at http://www.engr.washington.edu/epp/psgb/2007psgb/2007proceedings/papers/1e_norri.pdf, Olympia Washington (viewed on 7 Feb 2008).

Palsson, W. A., J. Beam, S. Hoffmann, and P. Clarke. 2004. Fish without borders: trends in the status and distribution of groundfish in the transboundary waters of Washington and British Columbia. *In* T. W. Droscher and D. A. Fraser (editors), Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Available online at http://www.psat.wa.gov/publications/03_proceedings/start.htm (viewed on 7 Feb 2008).

Pess, G. R., M. L. McHenry, T. J. Beechie, and J. Davies. 2008. Biological impacts of the Elwha River dams and potential salmonid responses to dam removal. Northwest Science 82 (Special Issue):72-90.

Pohl, M. 2004. Channel bed mobility downstream from the Elwha dams, Washington. The Professional Geographer 56:422-431.

Randle, T. J., J. Bountry, B. Jackson, and G. Smille. 2004. Elwha River restoration project draft sediment management and monitoring plan, based on recommendations of the Elwha River Physical Processes Monitoring Workshop, 13-17 August, 2001, Port Angeles, WA. U.S. Department of the Interior, Bureau of Reclamation, Denver, CO and National Park Service, Fort Collins, CO.

Schwartz, M. 1972. Spits and bars. Dowden, Hutchinson, and Ross, Publishers. Stroudsburg, PA.

Schwartz, M. 1994. Beach geomorphology at the Elwha River delta in connection with removal of the Elwha and Glines canyon dams. A report to the Lower Elwha Tribal Council, Coastal Geologic Consultants, Inc. Bellingham, WA.

Seavy, F. and G. Ging 1995. Marine Resources of the Elwha River Estuary. USFWS, North Pacific Coast Ecoregion, Olympia, WA.

Shaffer, J.A. 2000. Seasonal variation in understory kelp bed habitats of the Strait of Juan de Fuca. Journal of Coastal Research 16:768-778.

Shaffer, J. A., R. Moriarty, J. Sikes and D. Penttila. 2003. Nearshore habitat mapping of the Strait of Juan de Fuca: Phase 2. Final report to the Northwest Straits Commission, Clallam Marine Resources Committee, and Washington Department of Fish and Wildlife. WDFW, Olympia, WA.

Shaffer, J. A. 2004. Nearshore mapping of the Strait of Juan de Fuca: II. Preferential use of nearshore kelp habitats by juvenile salmon and forage fish. *In* T. W. Droscher and D. A. Fraser (editors), Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Available at http://www.psat.wa.gov/Publications/03_proceedings/start.htm. (Viewed on 7 Feb 2008).

Shaffer J. A. , L. Ward, P. Crain, B. Winter, K. Fresh, and C. Lear. 2005. Elwha and Glines Canyon dam removals: nearshore restoration and salmon recovery of the central Strait of Juan de Fuca. *In* S. Brace and D. Fraser (editors), Proceedings of the 2005 Puget Sound Georgia Basin Research Conference 2005. Available online at http://www.engr.washington.edu/epp/psgb/2005psgb/2005proceedings/index.html (viewed on 7 Feb 2008).

Shaffer, J. A., D. Penttila, M. McHenry, and D. Vilella. 2007. Observations of eulachon, *Thaleichthys pacificus,* in the Elwha River, Olympic Peninsula Washington. Northwest Science 81:76-81.

Simenstad, C, M Logsdon, K. Fresh, H. Shipman, M. Dethier, J. Newton. 2006. Conceptual model for assessing restoration of Puget Sound nearshore ecosystems. Puget Sound Nearshore Partnership Report No. 2006-03. Published by Washington Sea Grant Program, University of Washington, Seattle.

Simenstad, C. A., R. M. Thom, K. A. Kuzis, J. R. Cordell, and D. K. Shreffler. 1988. Nearshore Community Studies of Neah Bay, Washington. FRI-UW-8811, University of Washington Fisheries Research Institute, Seattle.

Strickland, R. 1983. The Fertile Fjord. Sea Grant Publications, University of Washington Press, Seattle.

Stolnack, S. and R. Naiman. 2005. Summary of Research and Education Activities in the Elwha River Watershed and Adjacent Coastal Zone. University of Washington, Seattle.

Sweeting, R. M., R. J. Beamish and C. M. Neville. 2004. Juvenile salmon in Puget Sound and the Strait of Georgia. *In* T. W. Droscher and D. A. Fraser (editors), Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Available online at http://ww.psat.wa.gov/publications/03_proceedings/start.htm (viewed on 7 Feb 2008).

Thom, R. and L. Hallum. 1990. Long term changes in the areal extent of tidal marshes, eelgrass meadows, and kelp forests of Puget Sound. FRI-UW-9008, Fisheries Research Institute, University of Washington, Seattle.

Todd, S., N. Fitzpatrick, A. Carter-Mortimer, and C. Welle. 2006. Historical changes to estuaries, spits, and associated tidal wetland habitats in the Hood Canal and Strait of Juan de Fuca regions of Washington. State Point No Point Treaty Council, Kingston, WA.

Uncles, R. J. 2003. From catchments to coastal zone: examples of the application of models to some long-term problems. The Science of the Total Environment 314-316: 567-588.

U.S. Army Corps of Engineers (USCOE). 1971. Report on survey of Ediz Hook for beach erosion and related purposes. Part II. Seattle District Army Corps of Engineers, Seattle, WA.

VanBlaricom, G. R. and M. D. Chambers 2003. Testing a charismatic paradigm: Consequences of a growing sea otter population for nearshore benthic communities along the south shore of the Strait of Juan de Fuca. Washington Cooperative Fish and Wildlife Research Unit, Biological Resources Division, U.S. Geological Survey, School of Aquatic and Fishery Sciences, University of Washington, Seattle.

VanWagenen, R. F. 1998. Washington coastal kelp resources: Port Townsend to the Columbia River. A report to the Washington Department of Natural Resources, Olympia, WA.

VanWagenen, R. F. 1996. Washington Coastal Kelp Resources: Port Townsend to the Columbia River. Final report for the Washington Department of Natural Resources, Olympia, WA.

Ward, L., P. Crain, B. Freymond, M. McHenry, D. Morrill, G. Pess, R. Peters, A. Shaffer, B, Winter, and B. Wunderlich. *In Press*. Elwha River Fish Restoration Plan Developed Pursuant to the Elwha River Ecosystem and Fisheries Restoration Act, PL 102-495. NOAA Technical Memorandum NMFS-NWFSC#, Seattle, WA.

Warrick, J., G. R. Cochrane, Y. Sagy, and G. Gelfenbaum. 2008. Nearshore substrate and morphology offshore of the Elwha River. Northwest Science 82 (Special Issue):153-163.

Wunderlich, R. and C. Pantealeo. 1995. A Review of Methods to Re-Introduce Anadromous Fish in the Elwha River. U.S. Fish and Wildlife Service Fisheries Assistance Office, Olympia, WA.