Large-scale Dam Removals and Nearshore Ecological Restoration: Lessons Learned from the Elwha Dam Removals

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ABSTRACT

Large dam removals are emerging as an important ecosystem restoration tool, and they often have direct influence on the marine nearshore zone, but dam removal plans give little consideration to nearshore restoration. We provide an overview of the relationship between large-scale dam removals and nearshore restoration, using the Elwha dam removal project, in Washington State, United States, as a basis. The following steps are essential for incorporating nearshore restoration planning into future dam removals: 1) Conceptual and technical modeling of nearshore physical and ecological processes at the drift cell scale to define nearshore priorities and geographic areas to be conserved or restored; 2) Acquiring seasonal field data to inform models, including: water quality; sediment delivery volumes, timing, trajectory and composition; and basic fish community data such as abundance, size, species composition, and trophic components; 3) Mapping nearshore habitat areal extent and ecological function prior to, during, and after dam removal, including vegetation composition and invertebrate community composition; 4) Defining and addressing the implications of habitat barriers and fish management actions for nearshore ecosystem function prior to dam removal. Structures and hatchery practices that conflict with nearshore ecosystem function for wild species prior to, during, and after dam removal should be identified and eliminated; 5) Anticipating nearshore invasive species colonization as a result of dam removal; 6) Developing and implementing long-term adaptive management plans to ensure nearshore restoration goals are identified and met. These steps must begin as early as possible in the planning process.

Keywords: drift cell, habitat, hatcheries, salmon, watershed management

Restoration Recap

- Worldwide it is estimated that there are 40,000–47,000 large-scale dams. Many have had significant impacts to watershed and marine ecosystems. Large dams built in the last century are now deteriorating, and dam removal is increasing as a restoration tool. The Elwha dam removal project, on the Olympic Peninsula in the state of Washington, is the largest dam removal project to date.
- Nearshore habitats provide flood protection, water quality improvement, and critical habitat for fisheries. However, most dam removal plans do not adequately address nearshore restoration. Through restoration of the Elwha River nearshore environment, we developed important recommendations for future dam removals.
- Planning should include the nearshore ecosystem at all stages. Defining physical and biological linkages between nearshore ecosystems, drift cells, and ecological function is critical in meeting restoration goals of dam removal.
- Adaptive management of nearshore restoration and conservation must be early, ongoing, and integral to dam removal.

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As large-scale dam removals increase in frequency, the need to understand the best practices for nearshore restoration grows. The nearshore environment and habitats, hereafter called "nearshore", are defined as extending from the area of tidal influence in lower rivers and include riparian zones, offshore to a depth of 30 meters below Mean Lower Low Water (MLLW) (Shaffer et al. 2008). The nearshore encompasses a critical set of ecosystems connecting freshwater and marine corridors. Formed and maintained by complex hydrodynamic and sediment processes (Schwartz 1973, Pilkey and Cooper 2014), the nearshore can be highly variable ecologically. Examples of the nearshore include: mangroves, shallow coral reefs, estuaries, salt marshes, rocky intertidal, un-vegetated and vegetated tide flats, kelp beds, and rocky reefs (Bertness et al. 2014). Additionally, drift cells are a key feature that define the nearshore. An idealized drift cell consists of three components: a site that serves as a sediment source and origin (usually an erosional bluff); a zone of transport where sediment may be temporarily deposited alongshore; and a terminus area of deposition and transport (Jacobsen and Schwartz 1981).

The nearshore provides ecosystem services of flood protection, water quality improvement, and critical ecosystem function. In North America, iconic cod and salmon, including *Salmo salar* (Atlantic salmon), *Oncorhynchus tshawytscha* (Chinook salmon), *Oncorhynchus kisutch* (coho salmon), *Oncorhynchus mykiss* (steelhead trout), *Oncorhynchus clarkii* (cutthroat trout), *Oncorhynchus keta* (chum salmon), *Oncorhynchus gorbuscha* (pink salmon), and *Oncorhynchus nerka* (sockeye salmon), depend on the nearshore for the life history stages of migration, resting, rearing, and feeding. Forage fish, which support global fisheries valued at $11.3 billion, depend on the nearshore for the same life history phases as well as for spawning (Reeves et al. 1989, Fresh 2006, Penttila 2007, Simenstad et al. 2011, Shaffer et al. 2012, Martin 2014, Pikitch et al. 2014). The nearshore has also been documented as a limiting factor for survival of juvenile anadromous salmon as they transition to adult and offshore habitats (Greene and Beechie 2004).

The nearshore is economically valuable as well. According to Wilson and Liu (2008) the world's total economic value of coastal marine systems is estimated to be US $22 trillion. Global nearshore ecosystem services have yet to be calculated. Nearshore ecological services for lower British Columbia, Canada are estimated to be $30–60 billion a year (Molnar et al. 2012). Along the northwest coast of the United States, Washington State coastlines provide ecosystem services of $985 million to $4.4 billion per year (Flores et al. 2013, Flores and Batker 2014). These values will likely increase in the future concomitant with climate change due to increasing pressure on coastal and riparian areas.

Human development has concentrated along northeast Pacific shorelines for more than 13,000 years (Gustafson 2012). With non-Tribal settlement in the region, shorelines continue to be filled and armored, lower rivers channelized and diked, and large docks and piers built over water. Storm water from upland development is conveyed to the shoreline. Cumulatively, such development has resulted in a severe loss of nearshore habitat and a number of impacts to marine ecosystem function globally (Levin and Lubchenco 2008, Dugan et al. 2011, Pilkey and Cooper 2014). Disruption of nearshore hydrodynamics and related sediment processes is a central impact on the nearshore (Bottom et al. 2005, Rice 2006, Dugan et al. 2008). Hobson et al. (2001) documented that dramatic shifts in upland management can affect nearshore production.

Large-Scale Dams and the Nearshore

Large-scale dams (> 15 m in height) are well documented to have significant impacts on land margin form and functional processes by blocking fish passage and altering river flows and sediment delivery to the nearshore. Dams located hundreds of miles inland may have significant ecosystem scale impacts on the coast. Drinkwater and Frank (1994) provide an overview of the major types of impacts of in-river dams to marine fisheries of the Black Sea, San Francisco Bay, and Hudson Bay. The delta of the Ebro River, the largest river in Spain, has decreased in area, and its salt wedge has increased due to in-river dams that have disrupted sediment and hydrodynamic processes (Jimenez and Sanchez-Arcilla 1993). Holmquist et al. (1998) state that high dams have an impact on shrimp and non-native species colonization (WCD 2000). In the United States, sediment delivery to the Columbia River littoral system has been decreased by a factor of three and is now a fraction of pre-dam rates (Gelfenbaum et al. 1999). Slagel and Griggs (2008) have estimated that sand volume contribution to beaches in California has been reduced from dam impoundment by up to 50% since 1885. Bennett (2005) cites dams as a significant negative factor to the survival of federally listed smelt species in San Francisco Bay. Nobriga et al. (2005) revealed that dams reduced sediment delivery to the nearshore by approximately 50%.

Habitat impacts are not the only nearshore factors associated with large-scale dams. Salmon hatcheries have become prominent management features over the last 100 years to increase fish production in populations that have been decimated by habitat degradation and over harvesting (Waples 1991, Lichatowich and Lichatowich 2001). Fish hatcheries are a management tool often associated with large-scale dams and dam removal (Ward et al. 2008). However, research has shown that hatcheries actually impede watershed restoration by displacing wild fish stocks and diluting genetic rigor (Lackey 2000, Weber and Fausch 2003, Kaeriyama and Edpalina 2004, Naish et al. 2007). In the northeast Pacific, the release of juvenile *O. tshawytscha* and *O. kisutch* from hatcheries into lower rivers has been documented to negatively affect *O. keta* and *O. gorbuscha* populations (Johnson 1973, Cardwell and Fresh 1979), which is one of the reasons hatcheries are now being questioned as a true restoration tool (Gregory et al. 2002). The relationship between hatchery practices and nearshore function is still not fully understood.

Table 1. Large Dam Removal Projects environmental planning documents: Y = Included, N = Not included, M = Mentioned.

Dam Removal Project	Nearshore impacts of dam removal identified	Nearshore restoration associated with dam removal sufficiently scoped and additional actions, if any, prioritized	Citation
United States			
Elwha EIS	Y	M (mentioned, but not included in detailed planning)	U.S.DoI 1996, Ward et al. 2008
Matilija Dam EIS	Y	N	USCoE 2010
Klamath Dam Removal EIS and Reports	Y	N	US Departments of the Interior and Commerce 2012
San Clemente	Y	N	California Department of Water Resource 2012
Marmot Dam	N	N	FERC 2008
Searsville Dam	N	N	USFWS and NMFS 2012
France			International Rivers 2015
St Étienne du Vigan	N	N	
Kemansquillec	N	N	
Spain			International Rivers 2015
Robledo	N	N	

Restoration of the Nearshore

In the last 20 years, there have been increased efforts to restore degraded aquatic ecosystems, including the nearshore (Borja et al. 2010, McGraw and Thom 2011). In 2011 alone, in the United States, $316 million was allocated through the federal NOAA Restoration Office for ecosystem restoration (McGraw and Thom 2011), and the US Army Corps of Engineers is slated to allocate $337 million to aquatic ecosystem restoration over the next biennium (USACE 2014). The majority of this restoration funding is allocated to the nearshore, but if the restoration projects do not adequately address the causes of nearshore degradation, the efforts will be insufficient.

Restoration of the nearshore marine environment may range from independent, small-scale riparian plantings, shoreline vegetation and sediment enhancements, to large-scale, full ecosystem restoration events. Small- and medium-scale projects are often relatively straight forward and show clear improvements relative to unrestored areas (Toft et al. 2013). While these small marine restoration projects may result in an increase in acres of marine habitat or an increase in the abundance of an individual species, many projects do not consider the underlying causes of degradation. If the causal mechanisms are not understood, the "restoration" will provide little recovery to species and functions that would be present in an intact system, so they fail to achieve full ecosystem restoration (Powers and Boyer 2014). Without true ecosystem restoration, ecosystem services may not be restored, and the intended restoration will ultimately fail. It is therefore critical to appropriately scope nearshore restoration actions.

Ecosystem Based Management (EBM) is an emerging tool in conserving and protecting the world's vanishing coastal resources (Levin and Lubchenco 2008), including the nearshore (Browman et al. 2004, Barbier et al. 2008). To date, EBM tools have not sufficiently focused on functional linkages between nearshore ecosystems and watershed species management actions. Hatcheries have transitioned from a top EBM restoration tool to a controversial management issue for ecosystem restoration. Evidence suggests that interactions between wild and hatchery fishes may disrupt residence time and increase competition and predation on wild stocks (Levin and Williams 2002, Weber and Fausch 2003, Naish et al. 2007). The implications of hatcheries for the nearshore and the role that hatchery management plays in the ecological function of an estuary undergoing restoration and the nearshore have been inadequately researched and are thus poorly understood. Further, the interactions between hatcheries, dam removals, and nearshore ecosystem restorations are likely central to dam removal restoration success but are not currently considered in dam removal planning efforts (Table 1).

There are many compelling reasons nearshore restoration should be considered in the restoration planning and monitoring phases of dam removal. Reasons include: the loss of nearshore habitats worldwide; the long-term impacts of dams to the nearshore; the potential for nearshore ecosystem shifts from dam removals; and the potential for significant ecosystem-scale restoration opportunities associated with dam removals. The Elwha dam removal project provides our first opportunity to focus on the restoration response of nearshore ecosystems to dam removals (Table 1), and to inform planning processes for

Table 2. Nearshore restoration planning considerations to address key nearshore limiting factors of the Elwha drift cell relative to dam removal.

Nearshore linkage/Limiting factor action	Suggested planning actions appropriate to restore limiting factor associated with dam removals	What was done	Restoration planning gaps	Dam Removal Documents Referenced in Action and Gaps
Identify nearshore relationship to watershed restoration project.	Detailed review of physical and ecological nearshore implications.	Comprehensive call to action by community including nearshore technical and education workshop. Some project habitat review relative to sediment delivery to offshore areas and estimation of ecosystem response.	Workshop restoration recommendations not incorporated into project. No analysis relative to life histories of species key to watershed ecosystem restoration (salmon estuary phase, forage fish spawning, etc).	U.S. DoI 1996, Triangle and Associates 2004, Stolnack and Naiman 2005, Todd et al. 2006, Ward et al. 2008
Identify ecosystem function of nearshore, nearshore limiting factors and links to restoration to drift cell associated with large-scale dam removal.	Develop conceptual model to identify and prioritize nearshore limiting factors and relationship to dam removal. Identify data gaps.	Conceptual model developed. Key nearshore limiting factors of the drift cell identified: Sediment starvation from shoreline armoring and in-river dams; lower river alterations. Data gaps on general ecosystem function and physical processes in the nearshore identified. Some restoration issues identified through conceptual modeling by independent body (ENC).	No nearshore restoration specific planning in project. Elwha Nearshore Consortium (ENC) work began late in the dam removal timeline (2006) and was external to the formal planning processes.	Shaffer et al. 2008, McDonald and Harris 2013
Address priority data gaps to inform additional restoration planning.	Key data gaps for physical and ecological processes and ecosystem services addressed and restoration information gaps addressed.	General broad data gaps and questions on Elwha drift cell physical and ecological processes addressed. Sediment monitoring in lower river, delta, and offshore initiated. Ecological baseline information within the drift cell collected.	Much of the physical process monitoring and modeling work informative but not designed to address specific nearshore restoration planning questions (sediment trajectory and fate specific to shoreline and lower river alterations).	Norris et al. 2007, Shaffer et al. 2009, Shaffer et al. 2012, Quinn et al. 2013a and b, Parks et al. 2013, Flores et al. 2014, Rich et al. 2014, Weifferling 2014, Gelfenbaum et al. 2015, Parks 2015

Table 2., *continued*

Nearshore linkage/Limiting factor action	Suggested planning actions appropriate to restore limiting factor associated with dam removals	What was done	Restoration planning gaps	Dam Removal Documents Referenced in Action and Gaps
Use conceptual model and data to defining restoration projects linked to dam removal that address key nearshore restoration needs. Sediment starvation due to shoreline armoring, in-river dams resulting in loss of estuary habitat.	Sediment modeling to define sediment trajectory and fate, specific to shoreline actions to optimize sediment delivery. Removal of shoreline armoring, protection of existing nearshore habitats. Dike alternatives to promote hydrologic connectivity to estuary. Fish management actions to assure no impacting interactions.	Extensive nearshore sediment modeling and baseline physical and ecological monitoring. Relative contribution of river and bluff contribution to nearshore defined, and roll of armoring on sediment limitation identified. Data are important for beach spawning fishes in lower river and shoreline. A few specific recommendations for restoring estuary hydrodynamic processes.	Sediment modeling to date has not accounted for seasonal ecological function, or defined sediment trajectory or delivery to beaches along the drift cell. No restoration recommendations can therefore be generated from sediment monitoring for these ecosystem functions. General restoration needs and issues identified not included in dam removal planning. Not prioritized.	Shaffer et al. 2009, 2012, Parks et al. 2013, Rich et al. 2014, Weifferling 2014
Post dam removal assessment of nearshore restoration and next steps.	Dike of lower river continues to block fish access to remaining habitat and disruption of nearshore hydrodynamics; shoreline armoring remains along feeder bluffs and industrial waterline. No restoration actions; additional armoring has been added to shoreline since nearshore planning began.	Modifications scoped for flood protection and fish passage.	Only modifications for flood protection implemented on west levee. Dike was raised and widened, and additional armoring placed along dike and shoreline. No fish passage provided in dikes.	Corum 2009
Dam removal and post dam removal fish management practices in watershed confounding nearshore ecosystem use.	Delay hatchery release until *O. keta* migration over (June).	None	None	Peters et al. 1996

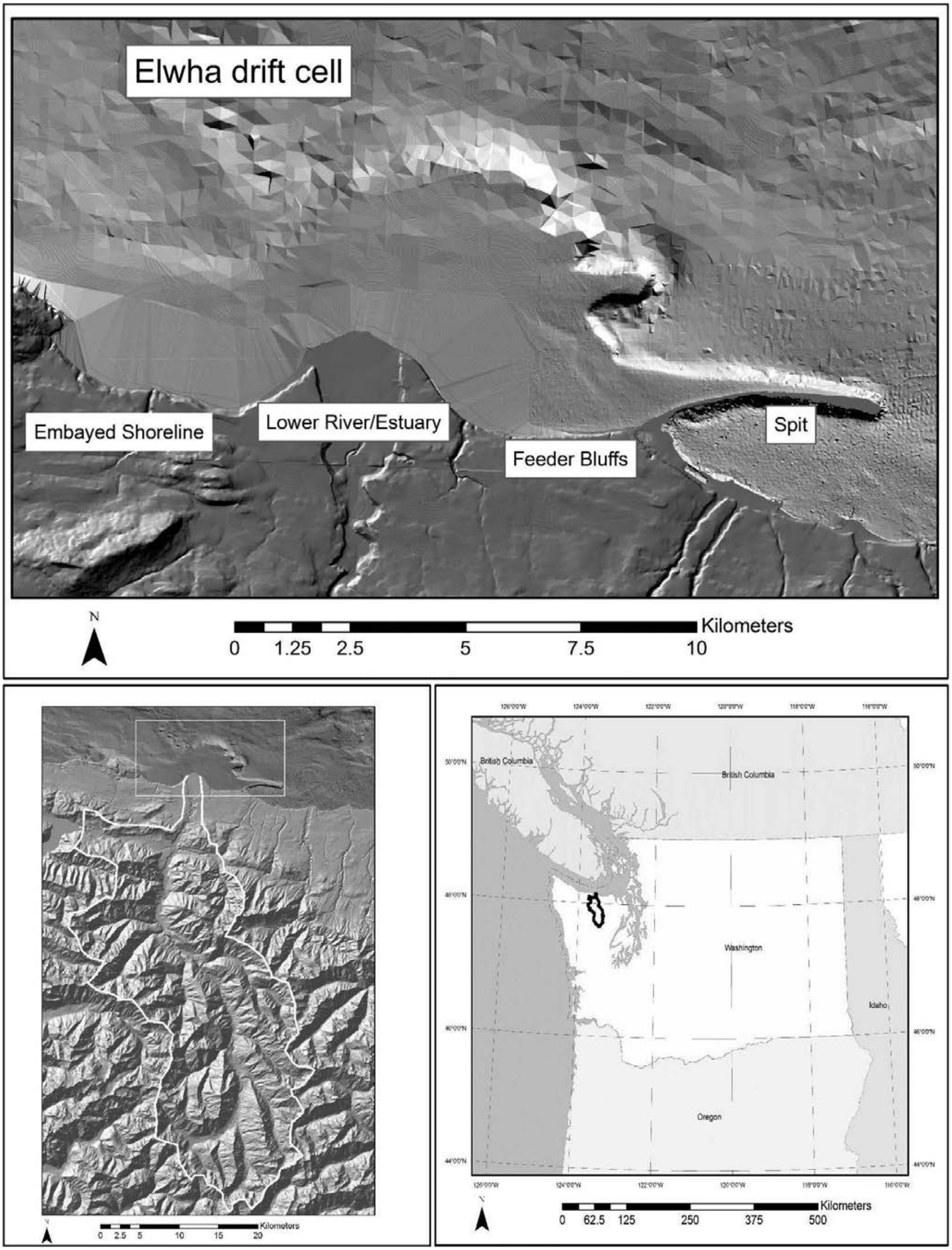

Figure 1. Elwha drift cell with landforms (top panel), watershed (bottom left) and geographic location North Olympic Peninsula, Washington State, USA. Map by Dave Parks, Washington Department of Natural Resources.

future restoration projects. Table 2 provides an overview of the limiting factors of nearshore restoration that were illuminated during the Elwha dam removal. Our objective in this paper is to provide an overview of the relationship between large-scale dam removals and nearshore restoration and to give specific guidance for future restoration actions since dam removal is becoming more common. The Elwha dam removal project provides the basis for our recommendations.

Elwha Nearshore Restoration

Located on the north Olympic Peninsula of Washington State, United States (Figure 1), the Elwha nearshore is severely sediment starved and ecologically impaired due to a number of anthropogenic impacts, including two large hydroelectric dams. Glines Canyon Dam (64 m tall) and Elwha Dam (33 m tall) were installed in the Elwha River at the turn of the previous century. The two dams were 21 km and 8 km from the nearshore, respectively (Figure 2). Major impacts to the Elwha nearshore ecosystem directly related to the dam removals include ongoing shoreline armoring, lower river alterations, and in-river dams (Shaffer et al. 2008). As a result, the Elwha bluff and spit beaches are steep, with coarsened substrate and more variable grain size than comparable intact drift cells (Parks et al. 2013, Parks 2015). Furthermore, dikes and shoreline-armoring remain after dam removal, resulting in only a partial restoration in the Elwha nearshore.

Ecologically, the impacts are significant. Forage fish spawning in the Elwha nearshore is significantly lower than in comparable drift cells (Weifferling 2014). The lower Elwha River hydrodynamics are disrupted from straightening of the river, lower river alterations, including dikes (Shaffer et al. 2008, 2009). Fish use in the Elwha estuary is also disrupted (Shaffer et al. 2009). While eelgrass bed distribution along the Elwha drift cell is not significantly different than that of comparable areas across the drift cell (Norris et al. 2007), kelp bed distribution has expanded significantly across the drift cell since the armoring of Elwha feeder bluffs during the installation of industrial waterline and dams (Barry 2013). Finally, due to anthropogenic pressures, the distribution, size, and density of large woody debris (LWD) of the Elwha nearshore is significantly lower than on unaltered shorelines (Rich et al. 2014).

While it is an impaired ecosystem, long-term monitoring has revealed that the Elwha nearshore is ecologically complex, diverse, and ecologically important for fish. Fish use of Elwha nearshore habitats is highly variable, seasonal, and driven by species life history (Shaffer et al. 2008, 2009, 2012). Numerous juvenile fish species using the Elwha nearshore are listed under the federal Endangered Species Act (ESA) as threatened or endangered, including *O. tshawytscha* and *O. kisutch* that originate from as far away as the Columbia and Klamath River systems (Shaffer

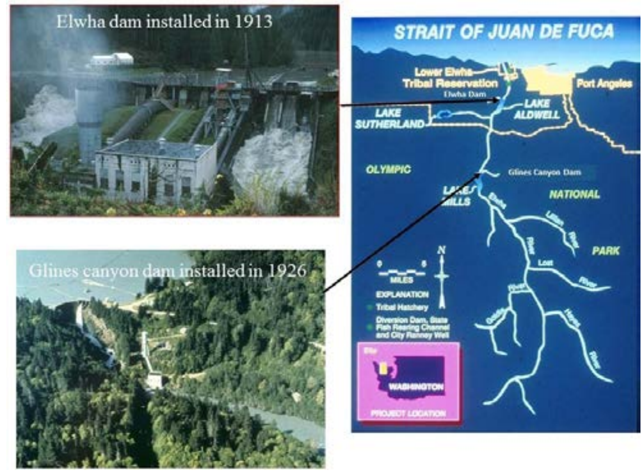

Figure 2. Elwha and Glines Canyon dams. After 25 years of planning, dam removal began in September 2011 and was completed August 31, 2014.

et al. 2012, Quinn et al. 2013a and b). Thus, nearshore restoration is important at an ecosystem level as well as at regional and larger scales. Pre-dam removal monitoring also indicates that hatchery practices, which result in upwards of 3 million salmon smolts being released into the Elwha nearshore during peak salmon out-migration, can seasonally overwhelm fish abundance in the estuary, shift fish species composition and abundance in the Elwha estuary, and eclipse seasonal wild out-migrating fish (Shaffer et al. 2009, Quinn et al. 2013a and b).

Twenty-five years after being legislated, the Elwha dam removal project began in September 2011 and concluded in September 2014. Approximately 20 million cubic meters (mcm) of sediment stored behind the dams are now being released into the watershed. Of this, approximately 10 mcm of silt, sand, and gravel material will be delivered to the nearshore (Gelfenbaum et al. 2015, Warrick et al. 2015, Randle et al. 2015) within five years of dam removal (U.S. DoI 1996, Shaffer et al. 2008). Extensive watershed restoration planning and monitoring work defined nearshore baseline conditions and monitored dam removal response (Duda et al. 2008, Duda et al. 2011, Warrick et al. 2015). But little scoping, planning, or implementation of nearshore restoration projects was achieved prior to, or during, the Elwha dam removals (Table 1). There was, to our knowledge, no funding for nearshore restoration relative to that for watershed restoration. Further, no adaptive management actions were in place to identify or address nearshore ecological issues identified prior to, or during, dam removals (Table 1). A few studies did recommend restoration of the nearshore habitats (Shaffer et al. 2009, Rich et al. 2014, Weifferling 2014), but these were unfortunately late in the dam removal timeline, and largely independent of the planning and funding framework. Therefore, few of the recommendations were incorporated into the formal dam removal process (Table 2).

Figure 3. Elwha estuary and lower river before and after dam removals. A) Estuary in August 2010. *Photo credit: John Gussman*; **B) Estuary in April 2014.** *Photo credit: Tom Roorda*. **Mapping estimates indicate that the Elwha nearshore estuary and lower river habitat has grown by approximately 80 acres (Shaffer et al. in press).**

In the Elwha, exhaustive project planning was done prior to dam removals to minimize sediment impacts to in-river fish migration. These included "fish windows," during which time dam removal was halted with the intent of minimizing sediment loads during fish use of the river. Planning, however, did not consider sediment delivery timing to the nearshore. As a result, the Elwha dam removal project could be a catastrophic disturbance event to the nearshore fish habitat, which is seasonally highly functioning (Shaffer et al. 2009). While detrital input from rivers is a significant source of detrital organic carbon for marine basins of the Salish Sea (El-Sabaawi et al. 2010), the short and dramatic nature of this sediment delivery may overwhelm the Elwha nearshore system and force an ecosystem shift to an alternative state of equilibrium (Levin and Lubchenco 2008). It is therefore critical to anticipate dam removal impacts specifically for nearshore function and in particular for fish use of the nearshore.

The Elwha dam removals were intended to result in restoration of the watershed ecosystem and the rebuilding of anadromous fish runs of the Elwha River (U.S. DoI 1996). However, at the beginning of the project, virtually nothing was known about how fish, including the many target species that have critical nearshore life history phases, would respond to the episodic and large volumes of sediment released into the nearshore. Much attention and decades of planning were dedicated to defining and prioritizing watershed habitat restoration projects in the Elwha River for a number of these salmon species (Ward et al. 2008, Quinn et al. 2013a). However, planning prior to dam removals did not identify or prioritize detailed nearshore restoration actions for these and other important species (Tables 1 and 2).

Based on the paucity of information on nearshore restoration aspects of large-scale dam removals and our career-spanning experience in the nearshore of the Elwha dam removal project, we provide the following recommendations. These are the critical nearshore planning, management, and monitoring elements to consider in nearshore restoration planning through future large-scale dam removals.

Recommendations for Incorporating Nearshore Restoration into Large-Scale Dam Removals

Link Nearshore Physical Processes and Ecosystem Restoration

Dam removals are intended to restore ecological function, largely through the restoration of physical ecosystem processes, including the nearshore. These physical processes therefore should be defined and monitored at both the watershed and drift cell scale and then evaluated and monitored for ecological function. This will require integrating key nearshore ecological elements, fish use in particular, into physical monitoring.

As stated by Parks et al. (2013), seasonal and inter-annual timing of sediment delivery to the intertidal along the entire drift cell and habitat, and direct linkage of this delivery to community changes within the nearshore, are critical to define for accurate understanding and restoration of the nearshore. This includes defining seasonal timing, volume, grain size and intertidal distribution of sediment delivery as well as nearshore habitat change associated with sediment delivery across the drift cell. This involves mapping habitat changes, not just sediment volumes. In the Elwha nearshore in 2013, two years after dam removal began, 65% of total retained sediment still remained in the watershed, and less than 12.5% of the 20 mcm of total estimated sediment that could potentially be released to the watershed had reached the nearshore. Some areas of shoreline aggraded only a few centimeters, while others grew by tens of meters (Gelfenbaum et al. 2015). However, when mapped for habitat coverage, these sediment volumes translate to upwards of 35 hectares (85 acres) of new lower river and estuary (Shaffer et al. in press, Figure 3).

It is also important to define, through pre-dam removal monitoring, nearshore basic water quality. Water quality parameters, including turbidity, temperature, pH, dissolved oxygen, and salinity, are critical components to understanding both physical and nearshore responses to large-scale dam removal. These data must be able to accurately reflect both seasonal and inter-annual changes in nearshore water quality. Monitoring must include both the original nearshore and newly created nearshore habitats, not just pre-dam removal sites. Concomitant data in comparable areas are critical to define dam removal from natural nearshore variability. East et al. (2015), Foley et al. (2015), and Draut and Ritchie (2015) documented that, as the river mouth of the Elwha extended, lower river habitat shifted from estuarine to non-tidally influenced lower river. This information is critical to understanding changes in fish use of the newly restoring nearshore.

Define Nearshore Habitat Associated with Dam Removals, and the Restoration Priorities

Nearshore ecosystem functions are linked across the drift cell**,** and species that use the watershed have critical nearshore life history phases. It is therefore critical to, in stepwise fashion, define the ecological condition, the ecological linkages with dam removal, and the subsequent nearshore conservation and restoration priorities of each land form within the entire drift cell, relative to dam removal. Nearshore habitats within the dam removal drift cell that are identified as intact and functioning properly should be a top priority for protection during and after dam removals.

Habitats that are defined as degraded should be prioritized and restored well prior to dam removal and protected after dam removal. This includes identifying and resolving important additional nearshore disrupting features within the dam removal drift cell. Nearshore habitat restoration from dam removals can be disrupted by dikes and shoreline armoring remaining in the nearshore during and after dam removal (Parks 2015). These features should therefore be clearly identified and incorporated as important components of large-scale dam removal restoration. Through long-term fish use monitoring in the Elwha, we observed that remaining dikes in the lower river appear to actually be preventing habitat restoration in the lower Elwha river by disrupting water flow and fish access to areas that could otherwise be critical refuges during high sediment flows (Shaffer et al. 2009, Shaffer et al., Coastal Watershed Institute, unpub. Data, Table 2).

Figure 4. Embayed shoreline of Elwha drift cell prior to and during dam removal. Dam removal began in September 2011, and concluded in September 2014. Substrate suitability for forage fish spawning increased dramatically in the lower river and embayed shoreline regions of the Elwha nearshore during the dam removal process, and persists now that dam removal is complete. A) Nearshore sampling Freshwater Bay, summer 2007. B) Nearshore sampling Freshwater Bay, summer 2013. *Photo credit: Anne Shaffer.*

Define the Key Ecological Processes of Nearshore Restoration Associated with Large-Scale Dam Removal

Monitoring long-term fish use of the nearshore is critical to understanding fish use response to dam removals. Through long-term beach seining of the Elwha nearshore, we found these newly created nearshore estuary areas are accessible and used by fishes almost immediately, including by species targeted for restoration, such as juvenile *O. tshawytscha*, *Hypomesus pretiosus* (surf smelt), and gravid *Thaleichthys pacificus* (eulachon) (Shaffer et al. in press). It is extremely important to thoroughly define the nearshore ecological aspects of dam removal restoration goals (for example, nearshore life history phases of salmon species, or key forage fish that they depend on) as well as the ecosystem restoration actions to protect and restore priority nearshore

Figure 5. Outstanding nearshore restoration needs of the Elwha including feeder bluffs (A), base of Ediz Hook (B), and lower river dikes (C). A1) Elwha feeder bluffs when first armored, 1929. *Photo credit: Dean Reed.* **A2) Elwha feeder bluffs, 2010.** *Photo credit: Anne Shaffer.* **B1) Base of Ediz Hook, spit formation that forms the terminus of the Elwha drift, ca. 1930s.** *Photo credit: Dean Reed.* **B2) Base of Ediz Hook, 2014.** *Photo credit: Anne Shaffer.* **C) Lower river dikes. West estuary dike blocks fish access to over half the original estuary. The unimpounded portion of the now lower river (1) continues to support high numbers of salmon and forage fish but may be filling in due to slowing of water flow due to the dike. The area impounded by the west levee dike (2) supports high numbers of resident fish indicating that if access was offered the area would be highly functioning for out migrating salmon (Shaffer et al. 2009).** *Photo credit: Anne Shaffer.*

ecological processes that will achieve these goals. The following are a few specific elements to define.

First, it is important to define nearshore fish community response to dam removal. Defining fish community composition, individual fish species abundance, and distribution within dam removal and comparable drift cells, using standard protocols before, during, and after dam removal phases, is important to provide critical information for planning the nearshore restoration aspects of dam removals. Ecological metrics for fish, including functional diversity and species richness, can provide important insight into additional restoration actions in the nearshore associated with dam removal. This should include all species important to the ecosystem, not just the commercially and recreationally important species.

Second, nearshore restoration, specifically for forage fish, should be identified. Beach spawning fishes have very specific sediment and habitat requirements for spawning, which make them excellent metrics to define nearshore restoration. For example, *H. pretiosus* spawning habitat along the Elwha beaches has been documented to be just a fraction of what is available along comparable drift cells, due to sediment starvation (Parks et al. 2013, Weifferling 2014, Figure 4A). Further, *T. pacificus*, which are river spawning smelt, were once common in the Elwha but are now documented to be in the Elwha River in low numbers, likely due to insufficient spawning habitat (Shaffer et al. 2007). Approximately half of the estimated 10 mcm of sediment that will be released to the Elwha nearshore is of a size appropriate for *H. pretiosus*, *T. pacificus*, and *Ammodytes hexapterus* (Sand Lance) (East et al. 2015, Gelfenbaum et al. 2015, Warrick et al. 2015). Anticipating trajectory, timing, and duration of delivery of appropriate grain size along the drift cell prior to dam removals could have greatly increased the effectiveness of our restoration planning and monitoring. Conversely, it is important to define the lack of an expected response to a restoration. For example, despite the abundant appropriate grain size material being delivered to the Elwha nearshore, sand lance, which spawn intertidally in winter along the comparative drift cell, have not yet begun spawning again along the Elwha shoreline (Weifferling 2014, Shaffer, Coastal Watershed Institute, unpub. data, Figure 4B). Delivery of the appropriate sediment is therefore not the only important consideration for dam removal restoration for this forage fish species. Nearshore restoration specifically for salmon species affected by dam removal is also an important planning focal point. All anadromous salmon have a nearshore life history phase which should be included extensively in dam removal restoration planning. In the Elwha, surprisingly, no project scale pre-dam removal planning or resources were allocated to identify, prioritize, or implement habitat restoration actions to restore the Elwha estuary for out-migrating salmon smolt. Therefore, the Elwha estuary continues to be constrained by a series of flood-control dikes, which appear to be disrupting nearshore restoration processes in the estuary (Shaffer et al. 2008, 2009, Figure 5).

Third, nearshore restoration and relationships with fish management practices are important aspects to include in dam removal considerations and planning. Interactions of hatchery and wild fish are well documented in other systems (Johnson 1973, Cardwell and Fresh 1979, Kaeriyama and Edpalina 2004). The role dam removal and the associated fish management practices will have on specific nearshore life history habitat functions, and how these relate to the larger ecosystem restoration, are therefore important to define. Hatchery release practices should be analyzed prior to dam removals, specifically to understand if and when released fish are recruiting to the nearshore and how these introductions will interact with wild fish use of the nearshore during critical habitat restoration phases. Hatchery release dates, species, and number of fish released relative to nearshore habitat use will define the interaction of hatchery releases to wild fish utilizing the estuary and nearshore, and allow managers to understand how management activities may translate to nearshore restoration response. If overlooked, fish management practices intended to promote ecosystem restoration could instead hamper restoration. In the Elwha, there are important potential interspecies interactions during *O. keta* outmigration with hatchery releases of juvenile *O. tshawytscha* and *O. kisutch*, which are known to have negative interactions with juvenile *O. keta*. This concern was the focus of initial study and hatchery recommendations to delay hatchery releases until after *O. keta* outmigration (Peters 1996). Unfortunately, these recommendations were not adhered to by state hatchery managers. On average over 3 million fish, including almost 2 million juvenile *O. tshawytscha* and 380,000 *O. keta* are released annually to the Elwha lower river during peak *O. keta* outmigration months (Quinn et al. 2013a and b). These fish are observed in the estuary in very high numbers (Shaffer et al. 2009). Given the large numbers of fish in a small estuary, there are likely interactions with wild fish (Shaffer et al. in press). Hatchery release practices should therefore be reviewed and revised specifically for species interactions and community effects in the nearshore prior to dam removals.

Finally, it is important to anticipate the potential and prioritize management for non-native/invasive species. Invasive species are well known to be able to monopolize newly created estuary habitat, at the exclusion of native species, with long-lasting and negative impacts (Powers and Boyer 2014). Because there is a paucity of effort on the nearshore, invasive plant species, such as *Cytisus scoparius* (scotch broom), have already been observed in the newly forming Elwha nearshore, and they are only now being addressed. Future dam removals should anticipate the establishment of non-native vegetation and fish species to prevent establishment and plan to act more proactively.

Develop Conceptual and Technical Models of Nearshore Physical and Ecological Processes

Conceptual and quantitative models are powerful and necessary tools to accurately integrate these elements to define the nearshore species, including specific life histories, and linkages to ecosystem processes that are the most impacted by dams. Models are an excellent way to define the highest nearshore restoration potential associated with dam removal. The models should encompass, at a minimum, the entire dam removal area and comparative drift cells, and they should focus at an ecosystem, not individual species, scale. The models should include all the dominant physical and ecological aspects of the drift cell and watershed that drive nearshore ecosystem function and interact with dam removal. They must also include, if any, a thorough analysis of the interaction of fish management practices in the watershed on nearshore function. Properly scoped, the models will be a powerful tool to define priority areas of restoration and geographic areas of the nearshore that have key information and action gaps. The scope of the nearshore conceptual model must include the highly seasonal and inter-annual variability of nearshore ecosystem function, as evidenced by long-term, seasonal pre-dam removal monitoring of both the nearshore and comparable drift cells.

Conclusions

Planning for ecosystem restoration of nearshore habitats is a critical component to large-scale dam removals. As evidenced by the Elwha dam removal project, future large-scale dam removal planning should comprehensively include the nearshore ecosystem, at a drift cell scale, as a priority before and during dam removal. This should be done through conceptual and quantitative modeling and field assessment of the physical and ecological nearshore of the dam removal site and comparable nearshore. Impediments to nearshore ecosystem processes, including habitat impairments and fish management tools, must be identified and critically reviewed for negative nearshore ecosystem restoration interactions. Given variability in nearshore systems, these steps should begin years prior to dam removals. Finally, as illustrated by the Elwha dam removal project, scoping large-scale dam removals can take decades. Science moves much more quickly than management, but managers must have the will to update plans to incorporate new information as it becomes available in order to ensure the best restoration outcome. Therefore, adaptive management should be an integral part of the restoration process for nearshore environments during dam removal planning and implementation. Early indications are that large-scale dam removals, including the Elwha dam removal project, appear to have many immediate and positive responses (O'Connor et al. 2015). However, without a prior, comprehensive, and long-term nearshore restoration plan, watershed restoration will be incomplete.

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References

Barbier E.B., E.W. Koch, B.R. Silliman, S.D. Hacker, E. Wolanski, J. Primavera, et al. 2008. Coastal ecosystem-based management with nonlinear ecological functions and values. *Science* 319:321–323.

Barry H. 2013. Long term kelp monitoring, Elwha nearshore. Proceedings, 8th Annual Elwha Nearshore Consortium (ENC) workshop. Coastal Watershed Institute, Port Angeles, WA.

Bennett, W.A. 2005. Critical assessment of the delta smelt population in the San Francisco Estuary, California. *San Francisco Estuary and Watershed Science* 3:1–71.

Bertness, M.D., J.F. Bruno, B.R. Silliman and J.J. Stachowiz (eds). 2014. *Marine Community Ecology and Conservation.* Sunderland, MA: Sinauer Associates.

Borja, Á., D.M. Dauer, M. Elliott and C.A. Simenstad. 2010. Medium- and long-term recovery of estuarine and coastal ecosystems: patterns, rates and restoration effectiveness. *Estuaries and Coasts* 33:1249–1260.

Bottom, D.L., C.A. Simenstad, J.A. Burke, M. Baptista, D.A. Jay, K.K. Jone, et al. 2005. Salmon at river's end: the role of the estuary in the decline and recovery of Columbia River salmon. National Oceanic and Atmospheric Administration Technical Memo NMFSNWFSC-68:246.

Browman, H.I., P.M. Cury, R. Hilborn, S. Jennings, H.K. Lotze, P.M. Mace, et al. 2004. Ecosystem-based Management. *Marine Ecology Progress Series* 274:269–303.

Cardwell, R.D. and K.L. Fresh. 1979. Predation upon juvenile salmon. Olympia, WA: Department of Fish and Wildlife.

Draut, A.E. and A.C. Ritchie. 2015. Sedimentology of new fluvial deposits on the Elwha river, Washington, USA, formed during large-scale dam removal. *River Research and Applications* 31:42–61.

Drinkwater, K.F. and K.T. Frank. 1994. Effects of river regulation and diversion on marine fish and invertebrates. *Aquatic Conservation: Marine and Freshwater Ecosystems* 4:135–151.

Duda, J.J., J.E. Freilich and E.G. Schreiner. 2008. Baseline studies in the Elwha River ecosystem prior to dam removal: introduction to the special issue. *Northwest Science* 82:1–12.

Duda, J.J., J.A. Warrick, and C.S. Magirl. 2011. Coastal and lower Elwha River, Washington, prior to dam removal—History, status, and defining characteristics. Pages 1–26 in J.J. Duda, J.A. Warrick and C.S. Magirl (eds), Coastal habitats of the Elwha River, Washington—Biological and physical patterns and processes prior to dam removal. US Geological Survey Scientific Investigations Report 5120:1–26.

Dugan J.E, L. Airoldi, M.G. Chapman, S.J. Walker and T. Schlacher. 2011. Estuarine and coastal structures: environmental effects, a focus on shore and nearshore structures. Pages 17–41 in E. Wolanski, D. McLusky (eds) *Treatise on Estuarine and Coastal Science*. Waltham, MA: Academic Press.

Dugan J.E., D.M. Hubbard, I.F. Rodil, D.L. Revell and S. Schroeter. 2008. Ecological effects of coastal armoring on sandy beaches. *Marine Ecology* 29:160–170.

East, A.E., G.R. Pess, J.A. Bountry, C.S. Magirl, A.C. Ritchie, J.B. Logan, et al. 2015. Large-scale dam removal on the Elwha River, Washington, USA: River Channel and floodplain geomorphic change. *Geomorphology* 228:765–786.

El-Sabaawi, R.W., A.R. Sastri, J.F. Dower and A. Mazumder. 2010. Deciphering the seasonal cycle of copepod trophic dynamics in the Strait of Georgia, Canada, using stable isotopes and fatty acids. *Estuaries and Coasts* 33:738–752.

Federal Energy Regulatory Commission (FERC). 2008. Bull Run Hydroelectric Project FEIS. 484 FERC Project No. 477-024, Washington, D.C

Flores, L., J. Harrison-Cox, S. Wilson, D. Batker, A. Shaffer and D. Parks. 2013. *Nature's Value in Clallam County: The Economic Benefits of Feeder Bluffs and 12 Other Ecosystems*. Tacoma, WA: Earth Economics.

Flores, L. and D. Batker. 2014. *An Assessment of the Value of Pacific County's Nearshore Ecosystems: Economic Data for the Shoreline Master Program Planning Process*. Tacoma, WA: Earth Economics.

Foley, M.M., J.J. Duda, M.M. Beirne, R. Paradis, A. Ritchie. and J.A. Warrick. 2015. Rapid water quality change in the Elwha River estuary complex during dam removal. *Limnology and Oceanography* 60:1719–1732.

Fresh K.L. 2006. Juvenile Pacific salmon in Puget Sound. Puget Sound Nearshore Partnership. Report No. 2006-06. U.S. Army Corps of Engineers.

Gelfenbaum, G, C.R. Sherwood, C.D. Peterson, G.M. Kaminsky, M. Buijsman, D.C. Twichell, et al. 1999. The Columbia River littoral cell: a sediment budget overview. *Proceedings of Coastal Sediments* 99:1660–1675.

Gelfenbaum, G., A.W. Stevens, I. Miller, J.A. Warrick, A.S. Ogston and E. Eidam. 2015. Large-scale dam removal on the Elwha River, Washington, USA: Coastal geomorphic change. *Geomorphology* 246:649–668.

Greene, C.M. and T.J. Beechie. 2004. Consequences of potential density-dependent mechanisms on recovery of ocean-type Chinook salmon (*Oncorhynchus tshawytscha*). *Canadian Journal of Fisheries and Aquatic Sciences* 61:590–602.

Gregory, S., H. Li, and J. Li. 2002. The conceptual basis for ecological responses to dam removal. *BioScience* 52:713–723.

Gustafson, C.E. 2012. The Manis Mastodon Site: An Adventure in Prehistory. *Washington State Magazine*. Washington State University. wsm.wsu.edu/s/we.php?id=318.

Hobson, L.A., M.R. McQuoid and V. Tunnicliffe. 2001. The Saanich Inlet basin: a natural collector of past biological, climatic and land-use changes in southwestern Canada amplified by results of ODP Leg 169S. *Geoscience Canada* 28:197–202.

Holmquist, J.G., J.M. Schmidt-Gengenbach and B.B. Yoshioka. 1998. High dams and marine-freshwater linkages: Effects on native and introduced fauna in the Caribbean. *Conservation Biology* 12:621–630.

International Rivers. Dam decommissioning. (accessed March 2015). www.rivernet.org/general/dams/decommissioning/decom3_e.htm.

Jacobsen, E.E. and M.L. Schwartz. 1981. The use of geomorphic indicators to determine the direction of net shore-drift. *Shore and Beach* 49:38–42.

Jimenez, J.A. and A. Sanchez-Arcilla. 1993. Medium-term coastal response at the Ebro delta, Spain. *Marine Geology* 114:105–118.

Johnson, R.C. 1973. Potential interspecific problems between hatchery coho smolts and juvenile pink and chum salmon. Olympia, WA: Washington Department of Fish and Wildlife.

Kaeriyama, M. and R.R. Edpalina. 2004. Evaluation of the biological interaction between wild and hatchery populations for sustainable fisheries and management of Pacific salmon. Pages 247–259 in K.M. Leber, S. Kitada, H.L. Blankenship and T. Svåsand (eds). *Stock Enhancement and Sea Ranching: Developments, Pitfalls and Opportunities*. Oxford, UK: Blackwell Publishing.

Lackey, R.T. 2000. Restoring wild salmon to the Pacific Northwest: chasing an illusion? Pages 91–143 in P. Koss, M. Katz (eds), *What we Don't Know About Pacific Northwest Fish Runs—An Inquiry into Decision-Making*. Portland, OR: Portland State University.

Levin P.S. and J.G. Williams. 2002. Interspecific effects of artificially propagated fish: an additional conservation risk for salmon. *Conservation Biology* 16:1581–1587.

Levin S.A. and J. Lubchenco. 2008. Resilience, robustness, and marine ecosystem-based management. *Bioscience* 58:27–32.

Lichatowich J. and J.A. Lichatowich. 2001. *Salmon Without Rivers: A History of the Pacific Salmon Crisis*. Washington, DC: Island Press.

Martin, K.L. 2014. *Beach-Spawning Fishes: Reproduction in an Endangered Ecosystem*. Boca Raton, Florida: CRC Press.

McDonald, J.M. and N. Harris (eds). 2013. Proceedings of the 8th annual Elwha Nearshore Consortium Workshop, Port Angeles, WA.

McGraw, K. and R. Thom. 2011. Protection and restoration: Are we having an effect? *Ecological Restoration* 29:2–8.

Molnar, M., M. Kocian and D. Batker. 2012. *Valuing the Aquatic Benefits of British Columbia's Lower Mainland: Nearshore Natural Capital Valuation*. Vancouver, BC: David Suzuki Foundation.

Naish, K.A., J.E. Taylor, P.S. Levin, T.P. Quinn, J.R. Winton, D. Huppert, et al. 2007. An evaluation of the effects of conservation and fishery enhancement hatcheries on wild populations of salmon. *Advances in Marine Biology* 53:61–194.

Nobriga, M.L., F. Feyrer, R.D. Baxter and M. Chotkowski. 2005. Fish community ecology in an altered river delta: spatial patterns in species composition, life history strategies, and biomass. *Estuaries* 28:776–785.

Norris, J.G., I.E. Fraser, J.A. Shaffer and C. Lear. 2007. Eelgrass mapping along the Elwha nearshore. Proceedings of the 2007 Georgia Basin/Puget Sound Research Conference. Olympia, WA: Puget Sound Partnership.

O'Connor, J.E., J.J. Duda and G.E. Grant. 2015. 1000 dams down and counting. *Science* 348:496–497.

Parks D.S. 2015. Bluff Recession in the Elwha and Dungeness Littoral Cells, Washington, USA. *Environmental and Engineering Geoscience* 2:129–146.

Parks D., A. Shaffer and D. Barry. 2013. Nearshore drift-cell sediment processes and ecological function for forage fish: implications for ecological restoration of impaired Pacific Northwest marine ecosystems. *Journal of Coastal Research* 29:984–997.

Penttila, D. 2007. Marine forage fishes in Puget Sound. Washington Department of Fish and Wildlife. No. TR-2007-03.

Peters, R. 1996. Emigration of juvenile chum in the Elwha River and implications for timing hatchery coho salmon releases. Olympia, WA: U.S. Fish and Wildlife Service.

Pikitch, E.K, K.J. Rountos, T.E. Essington, C. Santora, D. Pauly, R. Watson, et al. 2014. The global contribution of forage fish to marine fisheries and ecosystems. *Fish and Fisheries* 15:43–64.

Pilkey, O.H. and J.A. Cooper. 2014. *The Last Beach*. Durham, NC: Duke University Press.

Powers, S.P. and K. Boyer. 2014. Marine restoration ecology. Pages 495–516 in M.D. Bertness, J.F. Bruno, B.R Silliman and J.J. Stachowicz (eds). *Marine Community Ecology and Conservation*. Sunderland, MA: Sinauer Publishing.

Quinn, T., A. Shaffer, J. Brown, C. Byrnes, N. Harris and P. Crain. 2013a. Juvenile Chinook salmon, *Oncorhynchus tshawytscha*, use of the Elwha River estuary prior to dam removal. *Environmental Biology of Fishes* 97:731–740.

Quinn, T., N. Harris, A. Shaffer, C. Byrnes and P. Crain. 2013b. Juvenile coho salmon, *Oncorhynchus kisutch*, in the Elwha River estuary prior to dam removal: Seasonal occupancy, size distribution, and comparison to nearby Salt Creek. *Transactions of the American Fisheries Society* 142:1058–1066.

Randle, T.J., J.A. Bountry, A. Ritchie and K. Wille. 2015. Large-scale dam removal on the Elwha River, Washington, USA: Erosion of reservoir sediment. *Geomorphology*. 246:709–728.

Reeves, G.H., F.H. Everest and T.E. Nickelson. 1989. Identification of physical habitats limiting the production of coho salmon in western Oregon and Washington. Rep. PNW-GTR-245. Portland, OR: U.S. Forest Service.

Rice, C.A. 2006. Effects of shoreline modification on a northern Puget Sound beach: Microclimate and embryo mortality in surf smelt (*Hypomesus pretiosus*). *Estuaries and Coasts 29*:63–71.

Rich, S, J.A. Shaffer, M.J. Fix and J.O. Dawson. 2014. Restoration considerations of large woody debris in the Elwha River nearshore, Olympic Peninsula, Washington. *Ecological Restoration* 32:306–313.

Schwartz, M.L. (ed). 1973. *Spits and Bars.* Stroudsburg, PA: Dowden, Hutchinson and Ross.

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.

Shaffer, J.A., P. Crain, B. Winter, M. McHenry, C. Lear and T. Randle. 2008. Nearshore restoration of the Elwha River through removal of the Elwha and Glines Canyon Dams: An overview. *Northwest Science* 82:48–58.

Shaffer, J.A., M. Beirne, T. Ritchie, R. Paradis, D. Barry and P. Crain. 2009. Fish use of the Elwha estuary and the role anthropogenic impacts to physical processes play in nearshore habitat function for fish. *Hydrobiologia* 636:179–190.

Shaffer, J.A., P. Crain, T. Kassler, D. Penttila, and D. Barry. 2012. Geomorphic habitat type, drift cell, forage fish, and juvenile salmon: Are they linked? *Journal of Environmental Science and Engineering* 1:688–703.

Shaffer J.A., F. Juanes, T.P. Quinn, D. Parks, T. McBride, J. Michel, et al. (in press). Nearshore fish community responses to large scale dam removal: implications for watershed restoration and fish management. *Aquatic Sciences*.

Simenstad, C., M. Ramirez, J. Burke, M. Logsdon, H. Shipman, C. Tanner, et al. 2011. Historical change and impairment of Puget Sound shorelines: Atlas and interpretation of Puget Sound nearshore ecosystem restoration project change analysis. Puget Sound Nearshore Ecosystem Restoration Program (PSNERP) Technical Report 2011-01.

Slagel, M.J. and G.B. Griggs. 2008. Cumulative Losses of Sand to the California Coast by Dam Impoundment. *Journal of Coastal Research*, 24:571–584.

Stolnack, S., and R. Naiman. 2005. Summary of research and education activities in the Elwha River watershed and adjacent coastal zone. Seattle, WA: University of Washington.

Todd, S., N. Fitzpatrick, A. Carter-Mortimer and C. Weller. 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. PNPTC Technical Report 06-1.

Toft, J.D., A.S. Ogston, S.M. Heerhartz, J.R. Cordell and E.E. Flemer. 2013. Ecological response and physical stability of habitat enhancements along an urban armored shoreline. *Ecological Engineering* 57:97–108.

Triangle and Associates. 2004. Technical workshop on nearshore restoration Central Strait of Juan de Fuca. Seattle, Washington.

U.S. Army Corps of Engineers (2014). 2015. Fiscal year budget strong points. (accessed February 2015) www.usace.army.mil/Missions/CivilWorks/Budget.aspx.

U.S. Department of Interior (DoI). 1996. Environmental Impact Statement (EIS-2): implementation EIS, 1996. Elwha River ecosystem restoration implementation final environmental impact statement. National Park Service, United States Fish and Wildlife Service, United States Bureau of Reclamation, United State Bureau of Indian Affairs, United States Army Corps of Engineers, and Lower Elwha Klallam Tribe. federalregister.gov/a/04-25356.

U.S. Department of Interior and Commerce. 2012. Klamath Dam Removal Overview Report for the Secretary of Interior. (accessed February 2015). klamathrestoration.gov.

U.S. Fish and Wildlife Service and NOAA/National Marine Fisheries Service. 2012. Final environmental impact statement for authorization of incidental take and implementation of the Stanford University Habitat Conservation Plan. www.fws.gov/sacramento/outreach/2012/11-21/Docs/Stanford%20FEIS-Volume%201_Cover%20to%20Section%202-November%202012.pdf.

Waples, R.S. 1991. Genetic interactions between hatchery and wild salmonids: lessons from the Pacific Northwest. *Canadian Journal of Fisheries and Aquatic Sciences* 48:124–133.

Ward, L., P. Crain, B. Freymond, M. McHenry, D. Morrill, G.R. Pess, et al. 2008. Elwha River Fish Restoration Plan, developed pursuant to the Elwha River Ecosystem and Fisheries Restoration Act, Public Law 102–495. National Ocean and Atmospheric Administration Technical Memo, NMFS-NWFSC-90:168.

Warrick J.A., J.A. Bountry, A.E. East, C.S. Magirl, T.J. Randle, G. Gelfenbaum, et al. 2015. Large-scale dam removal on the Elwha River, Washington, USA: Source-to-sink sediment budget and synthesis. *Geomorphology* 246:729–750.

Weber, E.D. and K.D. Fausch. 2003. Interactions between hatchery and wild salmonids in streams: differences in biology and evidence for competition. *Canadian Journal of Fisheries and Aquatic Sciences* 60:1018–1036.

Weifferling, L. 2014. Forage fish spawning in a changing environment: restoring ecological form and function in the Elwha nearshore. M.S. Thesis, Evergreen State University.

Wilson, M and S. Liu. 2008. Non-market value of ecosystem services provided by coastal and nearshore marine systems. M. Patterson and B. Glavovic. Pages 119–139 in M. Patterson and B. Glavovic (eds), *Ecological Economics of the Oceans and Coasts*. Cheltenham, UK: Edward Elgar.

World Commission on Dams (WCD). 2000. *Dams and Development: A New Framework for Decision Making: The Report of the*

World Commission on Dams. Sterling, VA: Earthscan Publications. www.dams.org/report/contents.html.

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Water lily. Hagar G.J. 1916. *The Standard American Encyclopedia,* Volume 12. New York, NY: The University Society, Inc. The Florida Center for Instructional Technology, fcit.usf.edu.