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Functional diversity responses of a nearshore fish community to restoration driven by large-scale dam removal

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ABSTRACT

Large scale dams have numerous significant impacts on river and nearshore components of watersheds. Large scale dam removal is therefore an increasingly useful restoration tool that reestablishes physical processes and habitats that form nearshore ecosystems. Removing large scale dams will likely affect the functional ecology of nearshore ecosystems, but this concept has yet to be explored. Here we use data from a decade long study to define how the functional ecology of fish responded to large scale dam removal. Dam removal resulted in shifts in the nearshore through the reconnection of riverine and marine hydrodynamic system, large-scale and rapid creation of nearshore habitats, and a shift in nearshore habitats from tidally influenced to non-tidally influenced habitats. The functional diversity of the fish community within the system restored by dam removal was volatile during and after dam removal. Dam removal released sediment that formed new lower river and estuary. These new nearshore habitats supported a fish community of significantly greater functional dispersion and entropy relative to previously present beaches within and outside the new delta. That is, species unique in their diet, habitat use, morphology, and size were abundant relative to less functionally unique fish in newly formed beaches. These trends were temporary as there were no significant differences in functional diversity or entropy of fishes among sites after the restoration. Newly formed habitats proved to be more diverse but had lower resiliency after dam removal. Newly establishing nearshore sites appear more vulnerable to non-native and nuisance species that could disrupt the establishment of the watershed and shoreline. While functional richness at the original estuary sites dropped dramatically after dam removal, resiliency was higher after dam removal corresponding to a shift from estuary to lower river side channel habitat, indicating a more stable nearshore zone than new sites. We anticipate that functional diversity at the newly formed nearshore areas will stabilize as the habitats are vegetated and mature.

1. Introduction

Nearshore ecosystems are a critical 'connective tissue' that link marine and watershed ecosystems. In the northeast Pacific numerous endangered salmon and forage fish species depend on the nearshore zone for migration, foraging, refuge, and spawning (Simenstad et al 1982; Beck et al 2001; Shaffer et al., 2017a). Fish benefit from many features of shallow ecosystems (e.g., prey availability, predator refuge), and they are sensitive to anthropogenic disturbances (Munsch et al., 2016, 2017).

Large-scale dam removals are becoming an important tool for nearshore ecosystem restoration, but little is known about functional coastal response to large-scale dam removal (Shaffer et al., 2017a&b). In this study, we explore the long term functional diversity of fish communities of two estuaries on the north Olympic Peninsula, Strait of Juan de Fuca, with an emphasis on the functional metrics of the Elwha River estuary and the role of ecosystem restoration associated with large-scale dam removal in changing functional diversity. We detail the trait-based functional diversity and functional redundancy, and resulting functional stability of the Elwha estuary fish functional assemblage by species before, during, and after large-scale dam removals. The Elwha River dam removal project, which ended in 2014 resulted in 20 mcm of material liberated to the Elwha system approximately half of which is anticipated to be delivered to the coast within five years of dam removals.

We address the following questions:

1. What are the functional parameters of this regions nearshore

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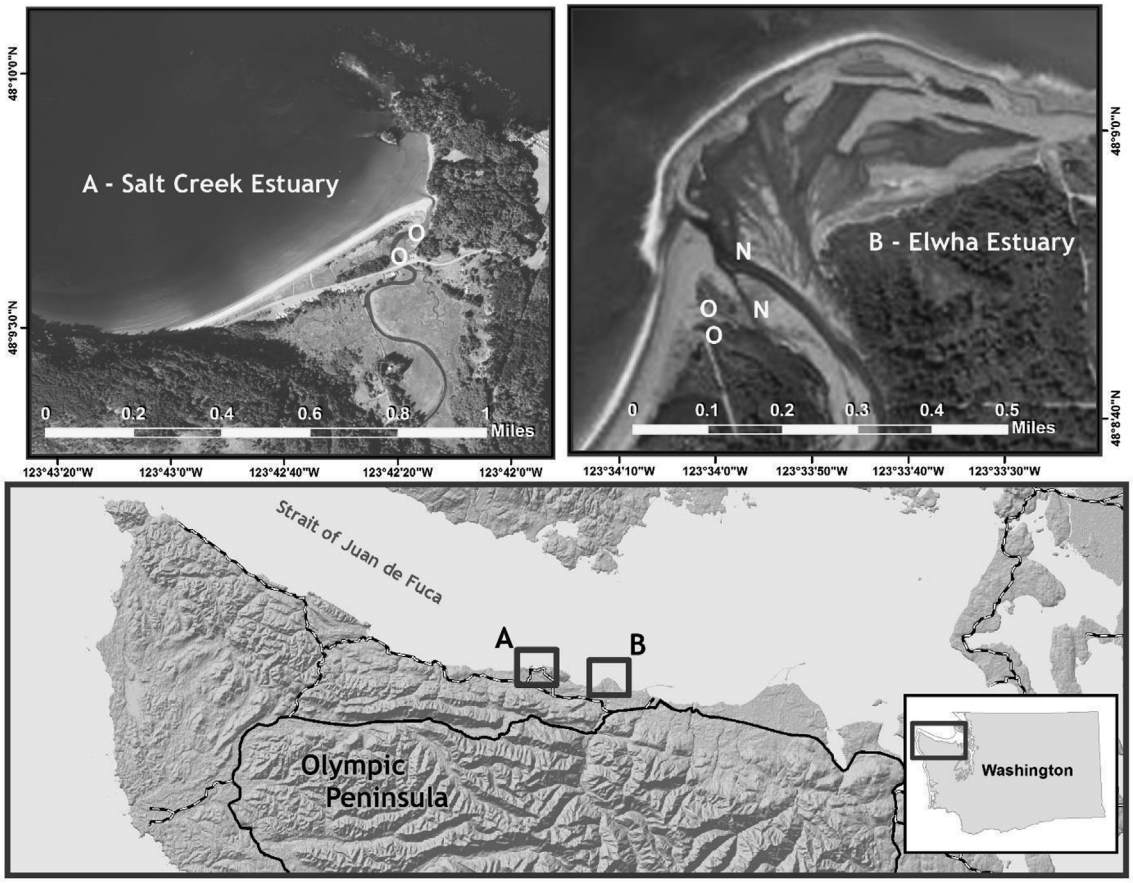

Fig. 1. A Salt Creek and B. Elwha River nearshore study sample sites. O original sites sampled 2008-present; N New sites created over the course of dam removals from delivery of dam removal sediment and sampled from 2013-present. Map by Terry Johnson, WDFW.

Table 1
Definitions of functional traits used in this analysis.

Metric	Definition	Citation
Functional richness	The amount of functional space occupied by a species assemblage	Laliberte et al., 2014
Functional dispersion	A multidimensional functional diversity matrix	Laliberte et al., 2014
Functional evenness	How regularly species abundances are distributed in the functional space.	Mouchet et al., 2010
Functional divergence	How far species abundances are from the center of the functional space	Mouchet et al., 2010
Rao's quadratic entropy (Q)	A distance matrix that defines the pairwise distances between species weighted by the relative abundance. Rao's Q takes into account abundances where functional richness cannot, thereby preventing overestimation of the influence of uncommon species	Bourdon 2016
Functional redundancy	The difference between species diversity and functional diversity. High redundancy indicates high stability and more resilience to ecosystem disruptions.	Guillemot et al., 2010, Kang et al., 2015

Table 2
The four trait categories used (Baptista et al., 2015).

Size	Small (< 70 mm)	1
	Medium (70–150 mm)	2
	Large (151–400 mm)	3
	Very large (> 400 mm)	4
Body transverse shape	< 0.5 (flat horizontally e.g. flatfish)	1
	0.5–1	2
	1–2	3
	> 2 (flat vertically e.g. perch/salmon)	4
Feeding guild	Omnivorous	1
	Planktivorous	2
	Piscivorous	3
	Zoobenthivorous	4
	Detritivorous	5
Vertical distribution	Benthic	1
	Pelagic	2
	Demersal	3

estuarine fish communities?
2. How do these functional parameters of the estuary fish community respond to ecosystem restoration associated with large-scale dam removal?
3. Are the functional elements of the estuary fish community more resilient after dam removals than before or during dam removal?
4. How does fish species community composition change functionally with dam removals?

Answering these questions will provide further understanding of ecosystem restoration, the functional linkages between nearshore coastal systems and large-scale dam removals, and how species assemblages may change functionally. All of these are important but poorly understood elements for future ecosystem restoration.