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THE HISTORY AND DECLINE OF *OSTREA LURIDA* IN WILLAPA BAY, WASHINGTON

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ABSTRACT With an annual production of 1500 metric tons of shucked oysters, Willapa Bay, WA currently produces more oysters than any other estuary in the United States. This production is mainly composed of the Pacific oyster (*Crassostrea gigas*), rather than the native Olympia oyster (*Ostrea lurida*). Historically, Willapa Bay was home to vast Olympia oyster beds, which formed the foundation of a major extractive fishery in the late 1800s. Yet the historical baseline extent of this habitat is poorly understood as it was first documented following decades of exploitation and was therefore based on a shifted baseline. An extensive and thorough literature review was undertaken to ascertain whether oyster beds mapped as "cultivated" in the 1890s were in fact originally wild beds. The most complete harvest statistics to date have been presented for the Olympia oyster in Willapa Bay (from 1849 to 2011) to provide useful historical insights into the expansion and collapse of the Olympia oyster fishery and discuss the evidence for numerous drivers of decline. Compelling evidence found that the historical extent of oyster beds in Willapa Bay may have been as great as 9774 ha, or 27% of the bay bottom, equating to a standing oyster biomass on the order of 3.6×10^6 kg. This figure is significantly greater that the often quoted ~2600 ha, derived if only beds marked as natural in the 1880s and 1890s are considered part of the original extent.

KEY WORDS: native oyster, restoration, historical ecology, overexploitation

INTRODUCTION

Beds of the native Olympia oyster *Ostrea lurida* (Carpenter, 1864) were a common feature of many Pacific coast (USA) estuaries during the Holocene (Stenzel 1971), until their ecological collapse during the late 1800s (Kirby 2004). The demise of Olympia oyster habitat was swift, brought on by high rates of exploitation and deforestation impacting estuaries (Holmes 1927, Galtsoff 1929). By 1920, most Pacific coast Olympia oyster fisheries had already collapsed (Kirby 2004), whereas the species persists as scattered individuals in a number of estuaries, *O. lurida* is now considered extinct as a habitat in estuaries south of Puget Sound (zu Ermgassen et al. 2012). The plight of the Olympia oyster has recently been recognized in Washington, where it is now listed as a species of concern by the Washington Department of Fish and Wildlife. Restoration efforts are increasing in both size and number along the Pacific coast (Cook et al. 2000, McGraw 2009, Blake & Bradbury 2012).

Increased interest in Olympia oyster habitat restoration has the potential to create conflict among user groups within estuaries, namely aquaculture and seagrass protection interests (Dumbauld et al. 2011, Blake & Bradbury 2012). Knowledge of the historical distribution and interactions between species within the estuary can provide an important evidence base for decision making in these circumstances. Unfortunately, although oyster beds in a number of estuaries were mapped in the late 1800s and early 1900s (Collins 1892, Townsend 1893, 1896, Fasten 1931, Bonnot 1936), there are no estuaries in Washington for which the pristine abundance of Olympia oyster is known. Furthermore, little is known about the nature of pristine Olympia oyster habitat, due to the lack of quantitative surveys and the degraded status of habitat remaining today.

Willapa Bay, WA, was once home to a large Olympia oyster industry (Ingersoll 1881, Collins 1892) but, as in many locations on the Pacific Coast, harvest had all but ceased by 1920 due to the collapse of the oyster population (White et al. 2009). Whereas there is considerable descriptive evidence of the oyster beds from the earliest days of large-scale exploitation (Swan 1857, Bush 1906, Espy 1992), quantitative mapping of oyster grounds in Willapa Bay did not take place until 1888 (Collins 1892). This early map distinguished between natural and cultivated beds, illustrating that it represented an impacted distribution. The map also contained no information as to the density of oysters within the mapped polygons, or definition of the mapped habitat. As such, it is a poor record of the historical baseline. Previous efforts to determine a historical baseline extent of Olympia oyster habitat within the bay have primarily relied on this delineation of natural beds (e.g., Ruesink et al. 2006, Dumbauld et al. 2011).

Historical baselines provide important context for management decisions (Swetnam et al. 1999), yet the full extent of change resulting from human interaction with the marine environment remains poorly understood due to a lack of baseline data (Roberts 2007). Without meaningful baselines, it can be difficult to interpret long-term changes, as well as modern day restoration successes. In this paper we draw on the wealth of qualitative and quantitative data available to construct the historical ecology of the Olympia oyster in Willapa Bay, WA. From this, the potential extent and importance of this habitat building species within the bay that can be used to inform present day restoration and management decisions were estimated. Although the current extent and importance of the Pacific oyster *Crassostrea gigas* (Thunberg, 1793) were not explicitly addressed, cultivation in Willapa Bay, the current environmental setting and abundance, and role of the Pacific oyster in the bay should also be accounted for in such decision making.

MATERIALS AND METHODS

A comprehensive review of historical literature was undertaken from which references to oyster bed locations, harvest, cultivation, and exports were extracted. Although historical records representing the same period were contradictory, the

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most robust and detailed records were favored. For example, quotes from persons directly involved with the oyster trade in Willapa Bay at the time were used in preference to reports made about the fishery decades later. Annual harvest statistics were sought and subsequently plotted to give insight to the timing and extent of exploitation. A timeline for the exploitation of Olympia oysters in Willapa Bay was constructed from the literature to provide context to the findings.

References to bed locations were used to verify the two earliest maps of the bay that delineated oyster beds: Collins (1892) and Townsend (1896). Both maps were drawn less than 40 y after the start of large scale exploitation in the bay and both maps identify beds as being either natural or cultivated. The identity of each bed represented in the historical literature was cross-referenced to ascertain whether there was evidence to confirm the identity of the bed as either natural or cultivated during the earlier stages of exploitation (~1850 to 1890). The historical map from Townsend (1896) was overlain and adjusted to match the shoreline features of Willapa Bay as displayed in Washington State Department of Natural Resources Aquatic Parcels layer (Washington State Department of Natural Resources 2012) using Geographical Information Systems methods in ArcGIS Desktop 10.1 (2012). Geo-referenced polygon shapefiles for the oyster beds identified in both maps were digitally created and spatial estimates determined in ArcMap.

There are no quantitative assessments of historical density or size distribution of native oysters in Washington State. The earliest available size and density data for natural beds of Olympia oyster were documented in Dimick et al. (1941), from Yaquina Bay, OR. Therefore, as in zu Ermgassen et al. (2012), these data were used to estimate the historical biomass of native oysters in Willapa Bay were used. The beds in Yaquina Bay were still harvested at the time and therefore likely represent a conservative estimate of both the density and the mean size of a pre-exploitation population in Willapa Bay. A shell height (SH) to dry tissue weight conversion: dry tissue weight $= 6 \times 10^{-6}$ $SH^{3.06}$ was applied, which was similarly derived from oysters from Yaquina Bay (M. Gray, unpublished data).

RESULTS

Harvest Statistics and Historical Context

Harvest statistics were located for 148 of the 162 y between 1849 and 2011, forming the most complete set of records to date for the Olympia oyster in Willapa Bay (Fig. 1). The exploitation and eventual demise of the native Olympia oyster in Willapa Bay as a natural and economic resource can be characterized in five phases (Fig. 1).

The initial phase of exploitation began in 1850, with the first trade in oysters via schooner from Willapa Bay (then called Shoalwater Bay) to San Francisco by a Captain Fielsted (Hittel 1882, Foote 1888, Sawyer 1922). The trade developed rapidly, with oyster commerce centers becoming established adjacent to large expanses of natural intertidal oyster beds at Bruceport in the late 1850s (Swan 1857) and at Oysterville in 1854 (Espy 1992, Stevens 2010; Fig. 2). Oysters were harvested from these beds by hand and with tongs and rakes, and transported to culling stations at higher tidal elevations, where market-sized oysters were sorted for storage at readily accessible tidal elevations (termed ''bedding''). The remaining shell and undersized

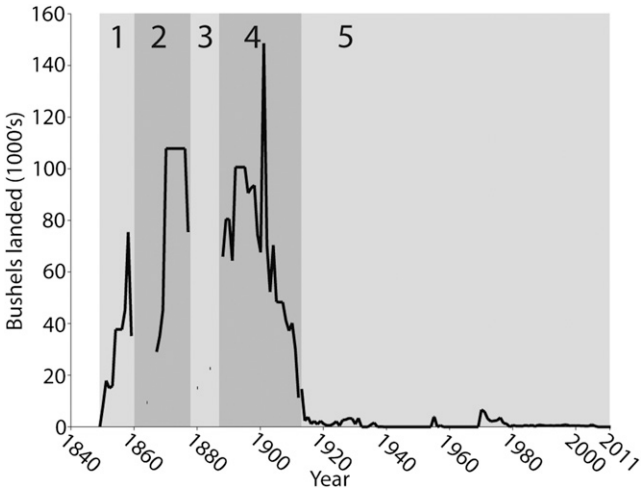

Figure 1. Olympia oyster landings in 1,000s of bushels between 1849 and 2011, where a bushel contains approximately 2,500 oysters (Hopkins 1937). Landing values were derived from the following publications: (Russel 1855, Swan 1857, Anon 1867, 1884, 1891, Evans 1877, Ingersoll 1881, Foote 1888, Collins 1892, Evans 1893, Townsend 1893, Little 1898, 1901, Kershaw 1902, 1904, Wilhelm 1902, Riseland 1907, 1909, 1911, 1913, Darwin 1916, 1917, 1919, 1921, Meeker 1921, Seaborg 1923, Pollock 1925, 1928, 1930, 1932, 1935, Galtsoff 1929, Brennan 1939, Washington State Department of Fish and Wildlife 1969, 2013, Espy 1992, Wiegardt 2000, PNCERS 2001).

oysters were simply deposited on site rather than being returned to the natural beds to maintain the supply of oysters (Espy 1992). Severe losses of bedded oysters from freezing weather in 1853 to 1854 (Swan 1857, Bush 1906, Espy 1992), coupled with the overexploitation of the targeted natural beds in the northern portion of the bay, led to an end of this initial phase of exploitation by ~1859 (Fig. 1). An estimated 312,545 bushels of market-sized oysters were known to have been harvested and shipped in this initial period of exploitation.

The second phase of exploitation (1859 to 1878) was initiated by the relaying of oysters from the natural beds surrounding Long Island (bed H, J, K and L; Fig. 2) and offshore of the Nemah river (bed M; Fig. 2) to the now cultivated beds adjacent to or in the near vicinity of Oysterville and Bruceport (beds B, C, D, E and F; Fig. 2). The industry was again affected by severe freezes, both in the early 1860s (1861 to 1862, 1863) and in the late 1870s (1875 and 1878; Bush 1906). The oyster trade at this stage again collapsed as a result of overexploitation and the effects of harsh winters (Weathers 1989, Espy 1992, Wiegardt 2000). The increased success in cultivating the Eastern oyster *Crassostrea virginica* (Gmelin, 1791) in San Francisco Bay and elsewhere may also have resulted in reduced demand for Willapa Bay Olympia oysters by the late 1870s (Ingersoll 1881). An estimated 1,141,064 bushels of market-sized oysters were known to have been harvested and shipped in this second period of exploitation (Fig. 1).

The third phase of exploitation from 1879 to 1887 is best described as an interlude during which the trade languished. By 1884, the natural beds were already reduced to around 2,590 ha (6,400 acres), located primarily in channels in the upper bay (Wilson 1884). Seed oysters continued to be harvested from the upper bay natural beds and relayed to cultivated beds in the lower bay and there was still no effort to return culled shell and

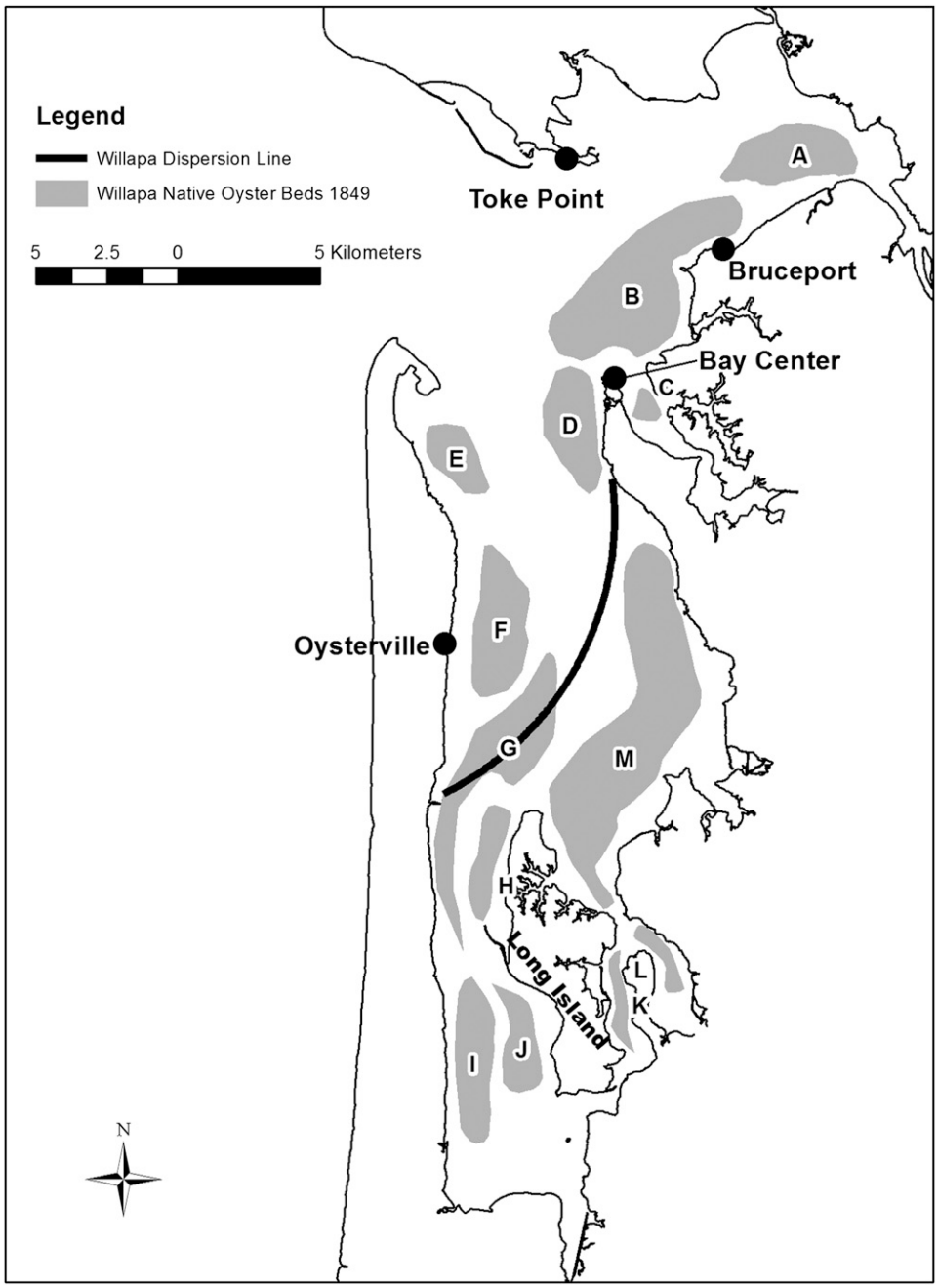

Figure 2. Map of historical natural oyster bed extent based on Townsend (1896). Oyster beds named as follows: (A) Willapa River, (B) Bruceport, (C) Bay Center, (D) Palix, (E) Stackpole, (F) Oysterville, (G) Mill Channel, (H) Long Island, (I) Bear River, (J) Smokey Hollow, (K) Long Island Slough, (L) Naselle, (M) Nemah.

undersized oysters to the exploited natural beds. Encroachment by eelgrass, a spatial competitor, and the increased availability of oysters from new markets (Bush 1906), may also have factored in the decline of the oyster trade that was described as ''well on its way to extinction by 1881'' (Gulick 1996). It was also noted during this period that harvested oysters declined in size (Ingersoll 1881). It was not possible to summarize harvests over this time period due to the paucity of harvest data, but the available information points to a vastly diminished trade. Newell (1884) noted that even in good years, annual production amounted to only 30,000 bushels in the early 1880s. No evidence was found that upward of 200,000 bushels were harvested annually in the 1870s as suggested by Cook et al. (2000).

The fourth phase of exploitation began in 1888 with resurgence in the harvest of market-sized oysters and the intensified gathering of seed from the remaining natural beds to be relayed to cultivated beds. In a last ditch effort to bolster the harvest, dredging for oysters was authorized by the state legislature in 1899, allowing the exploitation of deeper subtidal natural beds that had, with the exception of some poaching (Espy 1992), been previously unharvested (Bush 1906). The advent of dredging also heralded the advent of motorized boats,

with many of the sails being replaced by gas or naptha engines by 1905 (Allen 2013). Again, shell and undersized oysters were not returned to the exploited natural beds. After several years of recruitment failure, 1902 saw a peak extraction of 350,000 bushels of undersized "seed" oysters (Kershaw 1902), likely the result of a good recruitment event coupled with the legalization of dredging on subtidal beds. Around this time, both Collins (1892) and Townsend (1893) reported increased encroachment of eelgrass into oyster beds. An estimated 1,708,440 bushels of market-sized oysters were known to have been harvested and shipped in this fourth and final period of large-scale industrial exploitation. The fourth phase also saw the initiation of attempts to develop a fishery based upon the Eastern oyster, with seed imported by railway from the Atlantic coast (Townsend 1896).

The fifth phase (1913 to present) has been defined by the persistence of a relict and occasional trade in Olympia oysters. This phase also saw the decline of the Eastern oyster fishery in Willapa following die-offs due to unidentified causes between 1917 and 1919 (Sayce 1976). Although Eastern oyster production has sporadically continued in minute amounts in Willapa Bay (Washington State Department of Fish and Wildlife 1969, 2013), the Pacific oyster rapidly established a naturally reproducing population following its introduction from Japan in 1928 (Sayce 1976). The Pacific oyster was found to be more economically profitable due to its comparatively rapid growth and wider tolerance of a range of environmental conditions (Ruesink et al. 2005, 2006). The emphasis of the industry hence shifted as "People in Washington's oyster business began to look for other species to meet market demand as stocks of Olympia oysters declined," leaving the remaining Olympia oysters as biological and historical remnants (Lindsay & Simons 1997). Only an estimated 84,440 bushels of market-sized Olympia oysters are known to have been harvested from Willapa Bay from 1913 to 2011. Following the collapse of the native oyster industry in Willapa, the species continued to be intensively cultivated in lower Puget Sound, WA, for several decades until a similar decline occurred due to the effects of overharvest, pollution, introduced predators and pests, habitat alterations, and a shift to the more economically viable Pacific oyster (Steele 1957, Steele 1964, Fry 2011, Blake & Bradbury 2012). Only minor quantities of cultivated Olympia oyster are currently produced in lower Puget Sound (Lindsay & Simons 1997).

Historical Mapped Extent

No evidence was found that beds marked as natural beds on either the Collins or the Townsend maps had arisen from cultivation. There was, however, evidence that a substantial number of beds identified as cultivated in the late 1800s were originally natural beds that became depleted and were therefore strongly managed prior to the first mapping undertaken in the 1880s. Although "bedding" of oysters is referred to as early as 1853 (Bush 1906, Espy 1992, PNCERS 2001), this activity referred only to the manipulation of the natural beds offshore of Bruceport and Oysterville (Gibbs 1855, Espy 1992). All of the harvest prior to 1859 was reported as coming from natural beds. Transplanting from natural beds to cultivated beds did not occur until ~1859 to 1860 (Bancroft 1890, Victor 1891, Espy 1992).

The Oysterville bed (bed F; Fig. 2) was mapped by both Collins and Townsend as cultivated; however, numerous historical accounts state that the European settlement "Oysterville" was located due to its direct proximity to natural oyster beds (Bancroft 1890, Tompkins 1932). Furthermore, in April 1854, R. H. Espy, one of the first settlers on the bay, described being led by a local Indian chief to "mountainous beds of oysters" and "acres of oysters stretching farther north and south than the eye could follow" directly offshore from the eventual site of the oyster trade center of Oysterville (Espy 1992, Gulick 1996, Stevens 2010). Based on the description of both north and south extent, it is likely that both the Stackpole bed (bed E; Fig. 2) and Mill Channel bed (bed G; Fig. 2) were included in this account. In addition, Espy stated that there were only several hundred yards of open water separating the Oysterville beds from portions of the Bruceport trade center's beds in the 1850s (Espy 1992); this can only be the case if the Stackpole bed was considered part of the Oysterville bed complex, and Palix bed (bed D; Fig. 2), which was also mapped as cultivated, part of the Bruceport trade center's beds. Further support for the Palix bed being an original natural oyster bed comes from the Wilson family memoirs, which noted that George Wilson harvested off Palix in 1852 (Wilson 1973).

Bruceport bed (bed B; Fig. 2) and Willapa River bed (bed A; Fig. 2) were similarly both identified as cultivated by Collins (1892) and Townsend (1896), yet the settlement of Bruceport was established in December 1851 to be adjacent to the Bruceport and Willapa River beds (Swan 1857). Furthermore, numerous historical sources describe the initial harvest in the bay occurring upon extensive natural beds fronting first Bruceport, then Oysterville, followed by Bay Center (Swan 1857, Espy 1992, Gulick 1996, and sources cited in PNCERS 2001, Stevens 2010).

The historical extent of oyster beds in Willapa Bay was estimated to be as great as 9,774 ha, or 27% of the bay bottom (Table 1). This figure reflects the assumption that the extents mapped in the late 1800s were representative of the historical extent of formerly natural beds. It is possible that the extent at known locations may have been affected during the intervening decades of exploitation and cultivation and may therefore not represent the original areal extent. The extent given is therefore an estimate and not a quantitative, ground-truthed value. If the historical density and mean size was similar to oyster beds in Yaquina Bay, OR, as sampled in 1941 (density = 116 oysters m^{-2}, mean SH = 35 mm; zu Ermgassen et al. 2012), then the standing oyster biomass of Willapa Bay may originally have been in the order of 3.6×10^6 kg (Table 1).

DISCUSSION

Review of the historical literature clearly indicates that the natural pre-exploitation distribution of the Olympia oyster in Willapa Bay was more extensive than illustrated in either of the widely accepted historical maps by Collins (1892) and Townsend (1896). Previous estimates of historical extent have included ~2,600 ha (Ruesink et al. 2006) and 3,141 ha (Dumbauld et al. 2011), both of which were based on the historical Collins and Townsend maps, but included only the beds marked as natural at the time. These estimates were built on by zu Ermgassen et al. (2012), by including several of the beds marked as "cultivated" for which there was strong evidence of their existence in 1850, to reach an extent of 6,225 ha. It is possible that the area of the beds mapped had been increased through the activity of cultivators in intervening years as has been observed for the Eastern oyster in its native range (Brooks et al. 1884), reduced

TABLE 1.

Area and estimated biomass of Olympia oyster beds identified in the literature as natural in 1850, and mapped as a variety of bed types by Townsend (1896). ID gives the corresponding bed identifier used in Figure 2.

Bed name	ID	Area (ha)	Biomass (mt)	Bed type Townsend (1894)
Willapa River	A	720	266	Natural
Bruceport	B	1,817	671	Cultivated
Bay Center	C	78	29	Cultivated
Palix	D	629	232	Cultivated
Stackpole	E	345	127	Cultivated
Oysterville	F	801	296	Cultivated
Mill Channel	G	1,156	427	Natural
Long Island	H	309	114	Natural
Bear River	I	637	235	Natural
Smokey Hollow	J	374	138	Natural
Long Island Slough	K	137	51	Natural
Naselle	L	132	49	Natural
Nemah	M	2,639	975	Natural
Total		9,774	3,610	

by fishing, or either increased or decreased by storm activity. It cannot, therefore, be certain that the boundaries of the beds depicted as either cultivated or natural by Townsend and Collins reflect the true pristine area. Nevertheless, this revised estimate based on historical literature represents a further advance in the understanding of the potential historical importance and distribution of Olympia oyster habitat in Willapa Bay.

Review of the historical literature also provides insights into the timing and drivers of the decline in Olympia oyster habitat. In particular, the location and timing of the collapse of oyster beds allows the identification of the significant role played by exploitation of beds in the upper bay, the impact of harsh winters resulting in significant die-offs in the shallows, and the introduction of dredging as a legitimate harvesting method in sealing the fate of the Willapa Bay oyster beds.

From 1850 to 1920, exploitation pressure shifted spatially from the northern lower portion of the bay (i.e., near the mouth of the estuary) to the southern upper portion of the bay. Hydrodynamic models have illustrated a strong gradient of water retention within the estuary (Banas et al. 2007), whereas the lower bay is strongly influenced by tidal exchange and is therefore unlikely to retain larvae, the upper bay retains water (and hence local larval supplies) for 3–5 wk (Chapman & Esveldt 1943, Hedgpeth et al. 1981, Banas et al. 2007). Populations of oysters in the upper bay are therefore believed to be critical source populations (a reliable brood stock), versus the sink populations in the lower bay. This hypothesis is supported by the recent observation that Pacific oysters primarily set in the upper bay during the early stages of their establishment, but are now regularly setting in the lower bay (Dumbauld et al. 2011). The historical shift in exploitation of beds in the lower to the upper bay is therefore likely to have had a significant impact on the sustainability of the historical fishery during its expansion.

Olympia oysters are sensitive to extreme temperatures (Davis 1955, Trimble et al. 2009), allowing anomalous weather events to cause significant mortalities. Several winters in the historical timeline were noted for being exceptionally harsh (freezes: 1853 to 1854, 1861 to 1863, 1868, 1875, 1878, and 1888; storms: 1870 and 1875), each of which resulted in mass die-off on many shallow beds of Olympia oysters (Newell 1868, Hunter 1887, Sessions 1888, Bancroft 1890, Townsend 1893, Bush 1906, Sayce 1976, Weathers 1989, Espy 1992, Wiegardt 2000). With such events occurring in close proximity, the effects of overexploitation in this fishery were likely exacerbated. Historical texts also revealed the role of dredging in the latter days of the fisheries' decline (from 1899) in accelerating the collapse of the Olympia oyster fishery within Willapa Bay (Little 1901, Bush 1906). As all readily available natural oyster beds located in the intertidal and shallow subtidal throughout the bay became depleted, exploitation focused on the remaining deeper subtidal beds (Little 1898, 1901, Bush 1906), which had until then served as a *de facto* refuge. The exploitation of the last remaining remnants of the Olympia oyster population in the bay probably also contributed to the shift from a population of native oysters present and able to maintain itself in abundance, to one that persists as scattered individuals (Dumbauld et al. 2011). The shift from these subtidal populations acting as an important source of brood stock to themselves being substrate limited is still believed to persist currently (Trimble et al. 2009).

The historical texts, whereas not fully quantitative, also provided us with insights into the interactions between oyster beds and eelgrass beds, another important estuarine habitat. Collins (1892) and Townsend (1893) noted that eelgrass (*Zostera marina*) was encroaching on the overexploited oyster beds in the late 1800s and similar observations were made in the early 1870s after oyster beds were impacted by storms (Sessions 1888). The trend for eelgrass to replace impacted oyster beds appears to have persisted over time, with Dumbauld et al. (2011) determining that the vast majority of areas delimited by Collins and Townsend as natural oyster beds in the late 1800s are now occupied by eelgrass. It is clear, however, that eelgrass did not always completely exclude oyster beds, or vice versa, as the coexistence of oysters among eelgrass was also observed in numerous Pacific coast estuaries (Collins 1892, Kincaid 1920).

Understanding the interactions between habitats and their historical distributions is key to managing estuaries for recovery as opposed to relative to shifted baselines (Grossinger et al. 2005), as well as putting potential conflicts between estuary user groups into context. Conflict between eelgrass restoration and protection and oyster restoration has arisen in a few locations on the Pacific coast (e.g., Netarts Bay, OR; Archer 2008), where eelgrass is protected as Essential Fish Habitat. Such conflict possibly arises both as a result of a shifted baseline in expectations of the historical distribution of Olympia oysters in many estuaries, and because of a poor understanding of the ecosystem service values of Olympia oyster habitat relative to other critical habitat types. Although there is growing recognition that the historical state of ecological systems may no longer be culturally, environmentally, or economically appropriate as a restoration goal (Swetnam et al. 1999, Campbell et al. 2009), historical data should be considered among the suite of information used to inform management decisions, to ensure that modern management goals are not misguided (Swetnam et al. 1999).

Although this study does not provide us with any explicit insights into the ecosystem services provided by Olympia oyster habitat historically, it does provide a baseline from which services can be estimated once the services themselves are better understood (e.g., zu Ermgassen et al. 2013). An improved understanding of the historical baseline, the drivers of the original decline, and the historical

interactions between habitat types provide estuarine managers and those involved with habitat restoration with a firmer basis for debate. This work provides important insights into the historical importance of the Olympia oyster in Willapa Bay and hence the significance of including this habitat building bivalve species in the longer term vision of ecological restoration of the bay.

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