

Habitat Characteristics of an Intertidal Aggregation of Pacific Sandlance (*Ammodytes hexapterus*) at a North Puget Sound Beach in Washington

Abstract

Although the Pacific sandlance (*Ammodytes hexapterus*) is known to burrow into soft marine sediment to escape predation and conserve energy, few studies have examined its use of intertidal habitat in winter. I characterized intertidal sandlance habitat at a North Puget Sound beach in relation to tide height, oxygen concentration, and sediment size. The density of sandlance increased significantly as elevation in the intertidal decreased from 0.00/m² at 0.61 m above mean lower low water (MLLW) to 5.00/m² at -0.30 m below MLLW. There were no significant differences among depths to which sandlance were buried at three elevations (0.30, 0.00, and -0.30 m) in the intertidal zone (mean = 5.0 cm, range = 4.0 - 6.0 cm). The oxygen content of interstitial water at 0.30 m above MLLW tended to be lower at 6.0 cm (26.56 mm Hg) than at 4.0 cm (31.84 mm Hg) in depth but did not change during a low tide cycle when sediments were exposed to air. Additionally, there was no significant interaction between time of exposure and depth on interstitial water oxygen content. The oxygen tension of interstitial water at 0.30 m above MLLW was approximately one fifth of the saturated value (oxygen content of water in equilibrium with air) shortly after being exposed by receding tide and remained near this level until the site was re-inundated with the incoming tide. This oxygen level is near the suspected anaerobic metabolism threshold for sandlance. Disturbances that lower interstitial oxygen levels or change the size of beach sediments could adversely affect intertidal aggregations of sandlance.

Introduction

Pacific sandlance (*Ammodytes hexapterus*) is found in coastal areas with soft sediments along the eastern Pacific Ocean from southern California to the Bering Sea (Hart 1973). The sandlance is an important prey item for a wide variety of birds, fish, and terrestrial mammals (Clemens and Wilby 1961, Shepherd 1988). During summer, sandlance may burrow into soft marine sediment for short periods to avoid predation (Raey 1970, 1973). It also may burrow at any time when prey (zooplankton) are unavailable. Since the sandlance does not have a swim bladder, energy is required to maintain position in the water column. Thus burrowing may conserve energy (Winslade 1974, Pearson et al. 1984, Quinn 1987).

Sandlance may also burrow into sediment during winter for relatively long periods of time. Healy (1984) showed that captive sandlance spent nearly three winter months in sand before emerging in spring to spawn. Winslade (1974) suggested that *A. marinus* overwinter in sand and use fat reserves acquired the previous spring and summer for maintenance of metabolism. The mechanism(s) causing these fish to enter this overwintering stage

is still unknown, but Winslade (1974) suggested that it may be related to level of fat content in the fish and to local environmental factors such as low zooplankton density, low water temperature, and short day length.

Sandlance burrow into intertidal sediments of Puget Sound during winter months, presumably as part of an overwintering stage, although there is little information on this phenomenon. Sandlance aggregations may be susceptible to a variety of risks unique to their use of intertidal habitat such as predation from terrestrial predators (Dick and Warner 1982). In addition, disturbances that lower interstitial oxygen levels or change the size of beach sediments could reduce the ability of intertidal zones to support sandlance. However, to my knowledge no studies have examined how winter aggregations of sandlance use intertidal habitat in the Pacific Northwest. The objective of this study was to examine how sandlance use intertidal habitat during winter in relation to tide height, interstitial oxygen concentration, and sediment size.

Methods and Materials

Intertidal Distribution and Abundance

A pilot study was conducted in winter of 1985 to determine the general spatial extent of the intertidal

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sandlance aggregation at Clayton Beach. Clayton Beach is located in the southern portion of Larabee State Park on the northwest border of Skagit County, Washington (48°39'20" N Latitude and 122°29'30" W Longitude). I mapped 0.30 m elevation contours on Clayton Beach using a known elevation in the upper intertidal zone and a transit. All tidal elevations were based on mean lower low water (MLLW), which is the 19-year mean height of the lower of two daily low tides and defined as 0 m in elevation. Hereafter, all heights are in relation to MLLW. I began by digging holes (approx. 30 x 30 x 30 cm) at an elevation of 0 m in an area of intertidal zone where I had first located sandlance. I dug approximately 2 holes/m as I moved along the 0 m contour in both directions away from my starting point. I discontinued digging holes when I failed to find sandlance in the previous 15 holes. This transect gave me a crude estimate of the length (as measured along the shoreline) of the sandlance aggregation. To determine the width of the aggregation, I dug a series of holes (2 holes/m) along another transect perpendicular to the first transect. The second transect began at the approximate midpoint of the first transect and moved upslope. After locating the approximate upper elevational extent of sandlance on this transect, I dug a series of 5 continuous trenches (30 wide x 30 cm deep) from 0.30 - 0.65 m parallel to the second transect. These trenches were separated by approximately 10 m and evenly spaced along the length of the aggregation as determined by the first transect. My intent here was not to precisely measure the upper elevational limit of sandlance in this pilot study but rather to ensure that formal sampling (see below) would span the upper elevational range of sandlance. The pilot study showed that the upper elevation of sandlance was less than 0.61 m and concentrated in an area defined by approximately 50 m of shoreline (hereafter the study area). The study area was bordered by mud flats to the south and by a bedrock intertidal area to the north.

To determine how sandlance were distributed within the Clayton Beach study area, I used a stratified (by elevation) random sample design. In April of 1986, I established a 50 m transect along each of 4 elevation contours, 0.61, 0.30, 0.0, and -0.30 m. On each of the 4 transects, I randomly established 10 1m² plots in which I determined the density of sandlance. I constrained my study design such that half of the plots (5) per transect occurred

on each side of a line perpendicular to the contours that divided the study area into roughly two equal parts. In this way I ensured that plots did not occur in an overly clumped fashion (J. Skalski, University of Washington, personal communication).

At each plot, I marked a square 1 m² area and removed all sediment to a depth of approximately 30 cm while capturing all sandlance. I removed sediment starting at the edge of the plot and working toward the center to minimize the amount of sediment sloughing from the edges, although this was not a major problem. During the excavation of sediment, I also determined the depth (n = 5 per transect) to which sandlance burrowed. I determined burrow depth by measuring the distance from the sediment surface to the deepest ventral surface of the fish. Sandlance are oriented horizontally in the substrate. I had relatively small sample sizes of burrow depth, in part, because it was difficult to uncover and measure the depth of buried fish without disturbing them. Exposing the head or otherwise disturbing (e.g. vibrations) buried fish would cause them to vigorously flop about leaving little or no trace of their previous position. While this behavior did not prevent me from catching disturbed fish, it made measuring burrow depth impossible. I was limited to measuring the depth of the few fish whose posterior end was haphazardly (fortuitously) uncovered while the anterior portion remained in the sediment.

In each instance where I measured the depth of a sandlance, I also noted the depth of the anaerobic zone. I used the first noticeable change in sediment color from light gray in the aerobic zone to black in the anaerobic zone, based on ocular estimate, as the point at which the anaerobic zone began (Fenchel and Riedl 1970, Jørgensen and Fenchel 1974). My intent here was not to determine the depth of anaerobic layer per se, but to note where buried sandlance were located relative to that layer.

Interstitial Oxygen Tension

I determined the oxygen content of interstitial water at each of two randomly located sites along the 0.30 m elevation contour in the study area. I withdrew interstitial water from depths of 4 and 6 cm at each site three times during a low tide cycle; immediately after the receding tide first exposed

the sites, when the tide was at its lowest point, and just before the sites were re-inundated by incoming tide (approximately 2 hr intervals). I selected sites at 0.30 m because this was near the upper elevation of sandlance distribution, and depths of 4.0 and 6.0 cm because they represented the range of depths at which sandlance were found.

I sampled interstitial water using a 1 ml glass syringe connected to a modified needle with a short piece of latex tubing. The needle was made from a small diameter brass tube sealed at one end with solder and sharpened so that I could easily insert it into the sediment. Small bore holes, that allowed water but excluded sediment, were drilled into the tube near the sealed end. I inserted the needle to the appropriate depth and drew 0.95 ml of water into the syringe. The dead space in the needle and syringe (0.05 ml) had been previously filled with a saturated solution of NaCl, which has low gas solubility (Welsh and Smith 1960). After drawing a sample, I removed the needle, sealed the syringe with hematocrit sealer (wax), and stored the sample on ice for 2-6 hr. I determined the oxygen content of the water sample using a Corning Blood Gas Analyzer (model 175) and corrected the oxygen tension of the sample water for dead space volume in the syringe. To help determine if there was a decline in oxygen tension as a result of microbial respiration, I took two control samples of oxygen-saturated water from Clayton Beach using methods described above. One was held on ice for 2 hours while the other was held on ice for 6 hours. The oxygen tension of the 6 hr sample was 174.1 mm Hg versus the 2 hr sample of 177.8 mm Hg representing a decline of 2.1%. Based on this result, I assumed that the effect of microbial respiration on oxygen content of interstitial water was negligible.

I used nonparametric statistics when data were not normally distributed and when square-root transformed data (Zar 1984) did not improve normality as determined by Lilliefors test (Wilkinson 1992). I analyzed square-root transformed density (fish/m²) data using analyses of variance (ANOVA) and Fisher's Least-Significant Difference test (Wilkinson 1992), which allowed for comparisons between treatment pairs when overall treatment effects were significant (i.e. $P < 0.05$). I analyzed fish depth data using a Kruskal-Wallis one-way ANOVA, and interstitial oxygen data using a 2-way (depth x time) ANOVA.

Intertidal Sediment Size

I returned to the Clayton Beach study area in May 1998 to characterize the type of substrate in which sandlance burrowed. I collected eight, 1 kg sediment samples from holes dug along the -0.1 m elevation contour in the general vicinity where I worked in 1986. Samples were collected only from the aerobic layer, which occurs just above a color change denoting a shift to anaerobic conditions, and only from holes in which I located one or more sandlance. I assumed that sandlance were using the same types of substrate in 1998 as they had in 1986. Sediment samples were dried, sifted through a series of sieves (5.6, 2.00, 1.00, 0.50, and 0.36 mm), and weighed to the nearest gram.

Results

Abundance, Distribution, and Interstitial Oxygen

The density of sandlance increased significantly ($F_{2,27} = 16.09$, $P < 0.001$) as elevation in the intertidal decreased (0/m² at 0.61 m, 0.80/m² at 0.30 m, 2.40/m² at 0.0 m, and 5.00/m² at -0.30 m; Figure 1). There were no significant differences ($c^2_{0.05,2} = 2.70$, $P = 0.26$) among mean depths of sandlance at three elevations (Figure 1). Sandlance were found at a mean depth (pooled for all elevations) of 5.0 cm ($SE = 0.2$ cm, range = 4.0 - 6.0 cm) and were always found above the anaerobic layer as determined by ocular estimate.

The oxygen content of interstitial water tended to be lower at 6.0 cm than at 4.0 cm in depth ($F_{1,6} = 4.62$, $P = 0.08$) throughout the low tide cycle but did not differ as a function of time ($F_{2,6} = 0.72$, $P = 0.52$). Additionally, there was no significant interaction between time and depth ($F_{2,6} = 0.43$, $P = 0.67$; Table 1). The oxygen tension of interstitial water at 0.30 m was approximately one fifth of the level of oxygen-saturated water (oxygen content of water in equilibrium with air) shortly after being exposed by receding tide and remained near this level until the site was re-inundated with incoming tide approximately 4 hr. later.

Intertidal Sediment Size

The sediment diameter in which sandlance were buried varied in size from approximately 10 mm to less than 0.36 mm. The majority of sediment, approximately 85% by weight, was between 0.36 - 1.00 mm in diameter (Table 2).

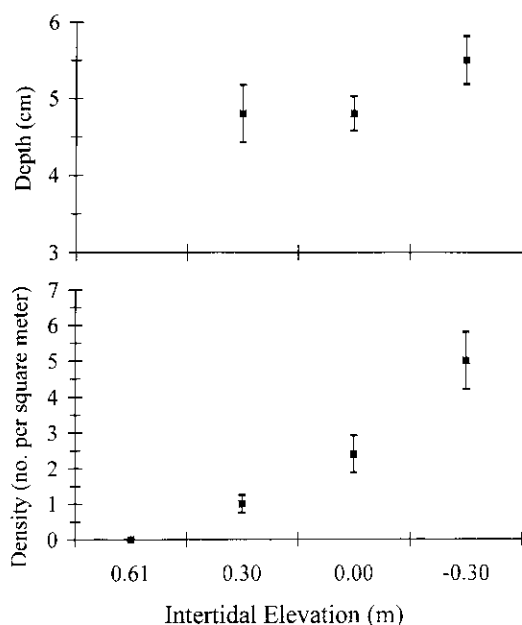


Figure 1. The density and standard error of sand lance (lower panel) and the depth and standard error to which sand lance burrow (upper panel) at Clayton Beach, Washington as a function of intertidal elevation.

TABLE 1. Mean oxygen content (and standard error), in mm Hg, of interstitial water from Clayton Beach at 0.30 m above MLLW as a function of time that elevation is uncovered by water during a low tide cycle.

Depth (cm)	N ¹	Cumulative time uncovered by water (min)		
		0	135	240
4.0	6	33.32 (5.95)	35.27 (1.01)	26.95 (3.90)
6.0	6	25.21 (0.47)	30.06 (1.53)	24.42 (0.42)

¹Two water samples were taken per depth per time interval.

TABLE 2. Proportions (by weight in grams) of different sized sediments in the intertidal habitat of sand lance at Clayton Beach, Washington, 1998.

Sediment Size class(mm)	Proportion by weight (n = 8)	
	Mean	Standard error
>5.6	0.34	0.84
2.00 - 5.6	1.47	0.32
1.00 - 2.00	4.42	0.65
0.50 - 1.00	65.27	6.01
0.50 - 0.36	21.30	5.69
< 0.36	7.19	1.27

Discussion

The sand lance is an important component of the marine food web in Pacific Northwest waters (Pinto et al. 1984). In spring, sand lance use the upper intertidal zone to spawn and spawning beaches (where sand lance eggs are found) are fairly common in the Puget Sound (Penttila 1995). However, few studies have looked at how winter aggregations of sand lance use intertidal habitat. It is unclear, for example, if the sand lance overwinters in the same beaches it uses for spawning (D. Penttila, WA Dept. Fish and Wildl., personal communication) or whether intertidal sand lance aggregations are contiguous with larger groups of sand lance using subtidal habitat. I examined several aspects of intertidal habitat use by sand lance in winter, but since this study was limited to a single aggregation, conclusions based on this work should be made cautiously.

Sand lance respire interstitial water when buried (Quinn 1987) and like most other fish species maintain oxygen consumption independent of the ambient oxygen tension down to some critical oxygen tension (P_c). Below the P_c , when oxygen becomes limiting, sand lance probably turn to anaerobic metabolism, which in most cases is a short duration strategy, to make up for shortfalls in the aerobic energy production (Hochachka and Somero 1984). Sand lance are probably incapable of surviving long when oxygen levels go below their P_c , approximately 15- 31 mm Hg depending on temperature (Quinn and Schneider 1991). In cases where extreme low tides correspond with unseasonably warm weather, sand lance may emerge from the exposed sediment (Dick and Warner 1982), presumably because oxygen becomes limiting (Quinn and Schneider 1991), and either desiccate or become easy prey for a host of predators. Warmer temperatures have a dual effect on oxygen content of interstitial water; decreasing the solubility of oxygen in water and increasing the rate of microbial respiration that can deplete oxygen from interstitial water (Johnson 1965). Thus, the severest test of hypoxia tolerance for intertidal sand lance aggregations probably occurs during daytime low tides when sand lance cannot escape to better oxygenated conditions of the water column if interstitial oxygen becomes limiting.

The factors determining the local distribution of intertidal aggregations of sand lance are poorly

understood (Raey 1970). Dick and Warner (1982) found that intertidal aggregations of sandlance in Alaska were often associated with stream or river mouths, and further observed sandlance in brackish water indicating a tolerance for low salinity. Anecdotal observation from this and other studies suggest that intertidal aggregations near Bellingham, Washington are patchily distributed (D. Penttila, Washington Department of Fish and Wildlife., personal communication): a pattern that may be related to requirements for specific types of intertidal habitat. Oxygenation of the sediment is undoubtedly an important component of intertidal sandlance habitat. Sandlance in the North Sea and off Nova Scotia are found associated with the edges of shallow sand banks where strong tidal currents maintain well oxygenated surface sediments (Macer 1966, Meyer et al. 1979). Pinto et al. (1984) showed that sandlance avoided silt while preferring sandy to gravelly substrate, a behavior they attributed to the greater availability of oxygen in sand. My study area was near the mouth of a small creek that goes subsurface when it reaches the beach. It is possible that this subsurface water helps make Clayton Beach suitable for intertidal habitat use by increasing the oxygen levels of interstitial water.

Sandlance were never found in the anaerobic sediment layer but rather occupied a narrow range of depths in the aerobic layer. Here, the sandlance experiences interstitial water with oxygen levels approaching its P_c . Although I could not show that the oxygen content of interstitial water was lower at 6 cm than at 4 cm in depth (i.e. $P = 0.08$), that conclusion is consistent with other studies of intertidal sediments (Gordon 1960, Brafield 1964). This narrow zone of habitat (4 - 6 cm) may represent a balance between the need for oxygen, which decreases with depth (although the effect of temperature may be inversely related to depth), and protection from surface predators which likely increases with depth. My results suggest that the oxygen content of interstitial water at Clayton

Beach was at equilibrium since it did not change over the course of the low-tide cycle. If the pattern of oxygen availability is similar at all elevations (consistent with lack of relationship between buried depth and elevation), then one way to minimize the risk of hypoxia and thus predation is to burrow at lower elevations in the intertidal zone since time of exposure (i.e., uncovered by water) is inversely related to elevation. This may explain why sandlance density was inversely related to intertidal elevation but begs the question; what advantages, if any, are gained from burrowing into intertidal sediments at higher elevations?

If oxygen in interstitial water is limiting for sandlance, disturbances that affect availability of oxygen may have important consequences for intertidal sandlance aggregations. Upslope disturbances such as logging and urbanization can add fine sediments to streams (Bilby 1985). If deposited near the mouths of streams, these fine sediments could fill interstitial spaces and thus reduce the flow of interstitial water. The addition of organic materials (e.g. sewage) can increase the water's biological oxygen demand, which may lower interstitial oxygen levels (Waldichuk 1977). The sorting and distribution of beach sediments is a dynamic process of deposition and erosion (Downing 1983). It is possible that as shorelines are developed, the sediment characteristics of beaches that support intertidal aggregations of sandlance will change. Our near term task is to understand how human disturbance affects important components of the near shore ecosystem which includes intertidal aggregations of sandlance.

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