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NEARSHORE DISTRIBUTION OF PACIFIC SAND LANCE (*AMMODYTES PERSONATUS*) IN THE INLAND WATERS OF WASHINGTON STATE

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ABSTRACT—Pacific Sand Lance (*Ammodytes personatus*) are energy-rich schooling fish that are thought to be important drivers of marine food webs in Alaska (USA) and British Columbia (Canada). Despite a number of studies characterizing their distribution and habitat use in Alaska and British Columbia, surprisingly little is known about population attributes in the Salish Sea. We compiled and analyzed 15,192 records collected from 1630 sites, primarily by beach seine or tow net in nearshore shallow areas between 1970 and 2009, to determine Sand Lance spatial and seasonal distribution in the inland waters of Washington State. Sand Lance were present along 78% of the shoreline that was sampled and were captured during every month of the year. The maximum number captured in individual nets increased between May and August. Fork length ranged from 1.7 to 19.0 cm and average fork length did not vary by month. The shortest minimum fork lengths were documented during April through July, likely representing annual recruits, but size at maturity is not known for the local population. Their widespread distribution throughout the region and peak abundance during summer suggests that they are an important potential prey source and could be a driver of marine food webs in this region.

Key words: *Ammodytes personatus*, Pacific Sand Lance, Puget Sound, Salish Sea

Pacific Sand Lance (*Ammodytes personatus*; Orr and others 2015) are energy-rich schooling fish (Van Pelt and others 1997; Anthony and others 2000) that constitute important prey for a variety of marine fishes, birds, and mammals, including federally listed vulnerable species (Hobson 1986; Robards and others 1999a; Bertram and Kaiser 1993; Trites and others 2007; Hipfner and Greenwood 2008; Williams and Buck 2010). In the Salish Sea, a 16,925 km^2 inland sea shared by Washington State (USA) and British Columbia (Canada) (Gaydos and others 2008), Sand Lance are thought to be a driver of marine food webs (Penttila 2007; Therriault and others 2009). Studies have shown that at nearshore sites in the region, juvenile Chinook Salmon (*Oncorhyncus tshawytscha*), a federally listed species, feed largely on larval and juvenile Sand Lance (Duffy and others 2010). Sand Lance also are the most numerically abundant prey in the diet of Lingcod (*Ophiodon elongates*), a recreationally important species, and comprise nearly 100% of the diet of Lingcod ≤30 cm (Beaudreau and Essington 2007). Additionally, they are one of the 2 most important prey for Common Murres (*Uria aalge*) and Rhinoceros Auklets (*Cerorhinca monocerata*; Lance and Thompson 2005), and can comprise up to 67% of the diet of Marbled Murrelets (*Brachyramphus marmoratus*) in regional populations (Norris and others 2007).

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There have been a number of studies characterizing the distribution and habitat use of Pacific Sand Lance in Alaska (Robards and others 1999b, 2002; Ostrand and others 2005; Johnson and others 2008) and British Columbia (Haynes and others 2007, 2008), but little is known about their population biology in the Salish Sea (Therriault and others 2009). Unpublished reports and observations from surveys of intertidal spawning sites and predator foraging habits suggest that Sand Lance are abundant in the region. Broadly distributed across the coastal northern Pacific Ocean, Sand Lance have been documented in nearshore surveys of fish species in Puget Sound, including the Strait of Juan de Fuca and San Juan Islands, since the early 1970s. Yet little biological information is available on this species in the region outside of intertidal spawning habitat use and a pilot study on oxygen and other intertidal habitat needs of buried Sand Lance at a single beach during winter (Quinn 1999).

Due to the fact that so little is known about the biology of Sand Lance in the inland waters of Washington, commercial exploitation of this species is prohibited by the Washington Department of Fish and Wildlife (Bargmann 1998). Consequently, unlike other forage fishes such as Pacific Herring (*Clupea pallasii*) and Pacific Surf Smelt (*Clupea pallasi*), stock structure and population assessments have not been conducted (Mitchell 2006; Stick and Lindquist 2009). The lack of basic biological information on this species could result in actions that lead to serious ecological consequences (Gaydos and others 2008), and efforts should be made to better understand the life history and distribution of Sand Lance. Although not specifically targeted for study in this region, Sand Lance are captured incidentally in beach-seine and townet surveys primarily designed to capture juvenile salmon (*Oncorhyncus* spp.). This retrospective review of nearshore Sand Lance data was conducted to summarize available information on the distribution, relative abundance, and size of Sand Lance in the inland marine waters of Washington.

METHODS

Beach seine and tow net data were gathered from a broad range of contributing sources, including federal, state, and county agencies, tribes, universities, private consulting firms, and non-profit organizations. These data were provided in a variety of formats and compiled into a single database. Data were most often recorded as the number of fish captured in a single net, hereafter referred to as an individual record or sample. One method for documenting captured fish is Catch Per Unit Effort (CPUE), calculated based on the number of fish captured and the time or distance covered by the net. Four of the studies that provided data for this project give CPUE data for Sand Lance, but for most studies CPUE could not be calculated. Therefore, all CPUE data provided were back-estimated to actual fish captured using tow rates, so that data could be combined. None of the final data in this paper are presented as CPUE. Presence-absence records were coded as Sand Lance present when fish were observed in the net and absent when none were observed, recognizing that "absence" does not mean that Sand Lance do not occupy a site, only that none were captured. Rate of capture could not be determined because not all contributors provided corresponding records for absence with those for presence.

Most data were recorded by contributing sources with Geographic Information System (GIS) location information of the sample sites; when latitude and longitude were not provided, approximate coordinates were assigned based on site names and descriptions provided by the corresponding researcher. For sites along the shoreline, the Washington Department of Natural Resources Shorezone Inventory was used. The inventory divides the shoreline into homogeneous physical segments, each approximately 0.5 miles long. Some areas with pocket estuaries have disproportionately short shorezone estimates, as the actual shoreline is longer than the assumed straight shore. Sites where sampling occurred were marked once within a single shorezone segment, and a percentage of total shoreline sampled was estimated based on the number of segments sampled. Sites using nets that were not cast from the shore were only included in a shorezone segment if the sample was taken within 40 m of the shore. This distance was calculated using ArcGIS.

A common gear type used for sampling juvenile salmon and Sand Lance is the Puget Sound Protocol Net, also referred to as a beach seine. This is a shore-based net deployed by boat and pulled back onto the shore by hand (Flewwelling 1995). A standard protocol beach seine has wings with 29-mm stretch mesh, a small bag at the cod end of the net lined with 6-mm stretch mesh, and covers approximately 40 m of shoreline (Miller and others 1990). Different habitats may require multiple gear types in a single study (Beamer and others 2007). Smaller beach seines, including 12-, 18-, and 24-m nets, were used in some studies to sample small coves or confined beaches. Additional net types included lampara, fyke, gill, and tow nets. Tow net refers to more than 1 net type, most often a small net towed by boat along the shore, but also a mid-water or surface trawl towed offshore (Flewwelling 1995). Tow nets were often used in conjunction with beach seines. Optimally, sampling Sand Lance requires a net that spans the entire water column and has a small mesh, because of the small size, slender body, and burrowing behavior of the species. Some gear types used in this analysis are potentially biased against smaller size classes because of escapement issues, and differences exist in capture rates and efficiency between net types.

Almost all Sand Lance data provided were supplemental to surveys directed at other species. The majority of beach seining was intended to capture salmon smolts in the nearshore, often accompanied by records of other fish species. Diurnal, seasonal, and tidal differences were not standardized, nor was sampling at sites repeated consistently. Although some metrics could be calculated for individual sites, significant areas were absent or not represented in this regional data set, precluding regional-scale analysis other than identification of presence or absence. The complications arising from a lack of standardized sampling methods preclude making estimates of biomass or population size, which should be goals of future studies.

RESULTS

We compiled 15,192 records collected between 24 March 1970 and 21 October 2009, from 1630 identified sites throughout the inland waters of Washington (Fig. 1). Various sizes of beach seines accounted for 90% of net types used for these studies. The other 10% of records were sampled with tow nets (7%), lampara (2%), fyke (<1%), gill (<1%), round haul (<0.2%), and trawl (<0.1%) nets. Mesh size for nets other than the Puget Sound Protocol Net were not provided. Latitudinal and longitudinal coordinates were provided for 1414 sites, and approximate coordinates were identified for an additional 216 sites, resulting in 1431 unique sites. Sand Lance were present in 21% of the records provided, which is an overestimate for rate of capture, as some contributors did not provide data on seines or tows where Sand Lance were not captured. The total amount of missing absence data was not provided. Beach seines and shallow-water tow nets captured Sand Lance 20% and 55% of the time, respectively.

Sites were separated into 7 watershed basins, as outlined by the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP; Anchor QEA 2009). Sampling effort was not uniform spatially or temporally, and Sand Lance beach-seine and tow-net data were available in only 6 of the 7 basins (Table 1). No data were available from Hood Canal. Whidbey Basin had the highest sampling effort, comprising 68% of all sites and 49% of all records, almost exclusively in Skagit Bay and the northern part of Whidbey Basin. The Strait of Juan de Fuca basin had the lowest sampling effort, with 14 confirmed sites.

Of Puget Sound's estimated 3970 km of shoreline, approximately 13% was sampled for Sand Lance (Table 2), which were present along 78% of the shoreline sampled. The percent of shoreline sampled at which Sand Lance were recorded varied by basin and ranged from 58 to 95%. Of 2833 stream mouths located along the shoreline of Puget Sound, 163 were sampled and Sand Lance were present at 49 (33%).

Sand Lance were captured during every month of the year sampled (Fig. 2). The maximum number captured in a single net increased between May and August, with all captures exceeding 4000 fish net^{-1} occurring only during these months. One capture >3000 fish occurred outside of these months (22 April 2009, Brown Point, southern Skagit Bay, Whidbey Basin), and no captures >1000 fish occurred between November and February. Of the 3222 samples containing Sand Lance, those >1000 fish were primarily conducted with a Puget Sound

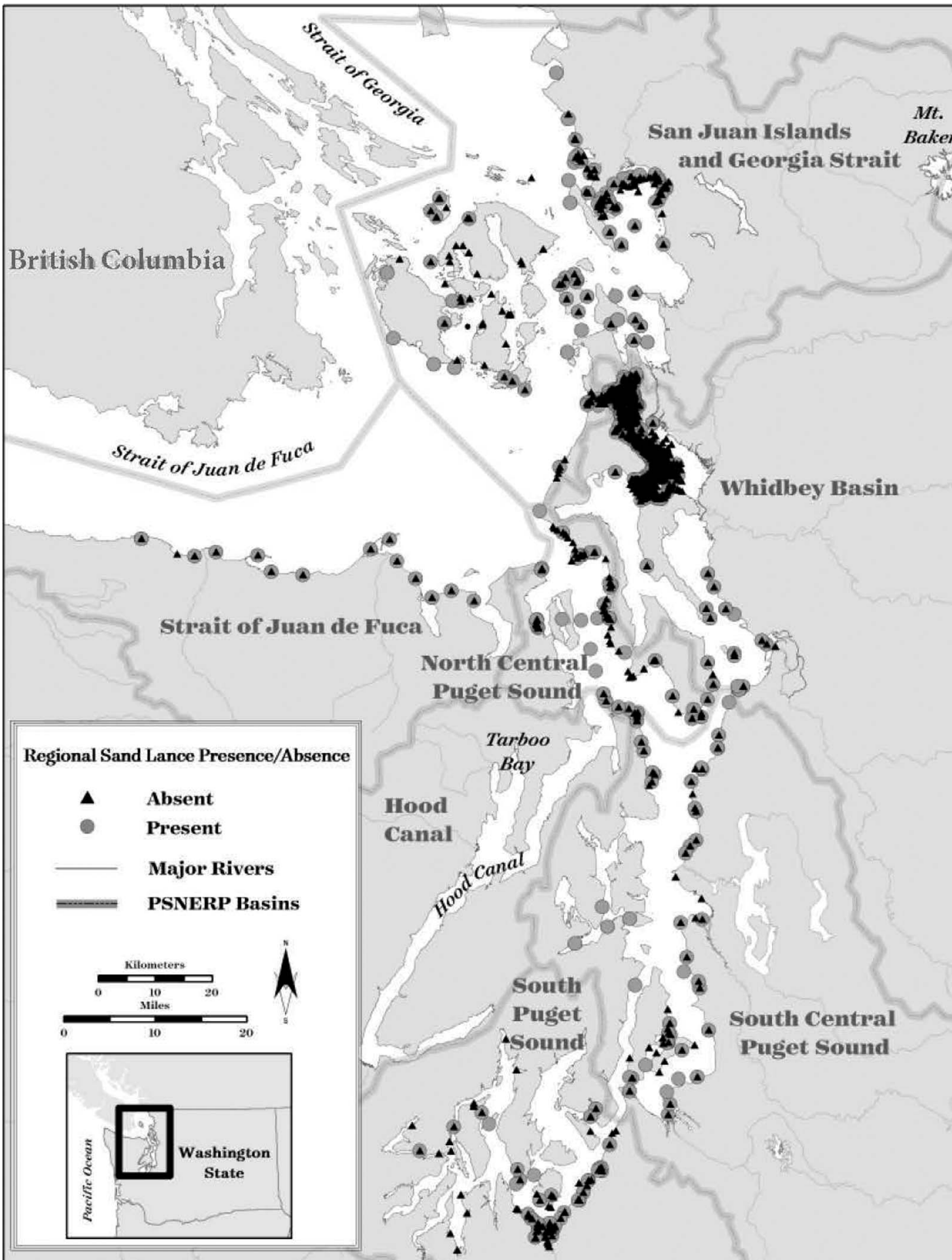

FIGURE 1. Sites sampled in the Puget Sound region, including sites where Pacific Sand Lance were captured (present) or not captured (absent). Sites with both markers denote multiple samples collected at the same location. Some records from surveys in the Strait of Juan de Fuca, San Juan Islands-Georgia Strait, Hood Canal, and South Central basins were not available for this analysis.

TABLE 1. Number of sites sampled for Pacific Sand Lance and individual records by watershed basin, 1970 to 2009. Sand Lance present mean that Sand Lance were captured in the net. Not all contributors provided data on Sand Lance absence.

Watershed basin	Sites	Total records	Records with Sand Lance present
North Central Puget Sound	84	1511	247
San Juan Islands/ Georgia Strait	202	1791	373
South Central Puget Sound	66	1176	177
South Puget Sound	92	2729	138
Strait of Juan de Fuca	14	496	128
Whidbey Basin	973	7489	2159
Total	1431	15,192	3222

Protocol Net (66 of 86 records), but also included one 12-m beach seine, two 24-m beach seines, 3 fyke nets, and 14 tow nets. Spatially, captures >1000 fish were scattered throughout 6 basins, but were more frequent in Whidbey Basin, North Central Puget Sound, and San Juan Islands and Georgia Strait basins (Fig. 3). These 3 basins comprised 87% of large captures. All captures >10,000 Sand Lance were from San Juan Islands and Georgia Strait (n = 4), Whidbey (n = 1), and North Central Puget Sound (N = 1) basins; all but 1 of these captures (3 May 2005, Mariner's Bluff, Whidbey Basin) were during June and July.

Fork length was measured for 820 of the 15,192 total records from 4 of the 7 watershed basins (Table 3), constituting about 1% of all Sand Lance captured since 1970. Net type can influence capture rates for fish of different lengths. Fork length ranged from 1.7 to 19.0 cm and average fork length did not vary by month, regardless of sample size. The range between maximum and minimum fork length increased with sample size (Fig. 4), yet mean fork length remained 8 to 10 cm. The shortest minimum fork lengths were documented during April through July. June and July were also the only months with median values >1 cm below the mean (1.2 and 1.5 cm respectively), while November was the only month with a median value >1 cm above the mean (1.6 cm). Median values for other months fell within 0.2 cm of the mean. The average monthly range between maximum and minimum fork length for each sample was between 2.0 and 2.5 cm for most months (average standard error = 0.39). The month of April had an average range of 1.59 cm (standard error = 0.23). This suggests that most fish caught were approximately the same size within an individual net.

DISCUSSION

Although not directed at Sand Lance, extensive nearshore fish surveys throughout the Salish Sea over the past 40 y demonstrate that Sand Lance are found throughout the region year-around, and in some instances occur in great abundance. Regional and annual distributions are known to fluctuate for many forage fish species, so site-specific presence of Sand Lance may vary seasonally. Despite the fact that field methods used were designed to primarily capture juvenile salmon, Sand Lance were still captured in all 6 basins where historical data could be found, often using a larger mesh size than is ideal for Sand Lance. Observations used for this survey are a minimum and likely underestimate the true distribution due to an inability to confirm absence versus false absence capture rates. Widespread distribution throughout the region suggests their importance as a prey source in nearshore habitats, more than would be expected from just their overall abundance alone (Zamon 2003). Our results demonstrate

TABLE 2. Shoreline sampled and results by watershed basin.

Watershed basin	Total shoreline (km)	Percent shoreline sampled	Percent shoreline sampled with Sand Lance present
North Central Puget Sound	211	36.97	73.08
San Juan Islands-Georgia Strait	1159	14.93	82.08
South Central Puget Sound	614	13.84	74.12
South Puget Sound	716	7.40	58.49
Strait of Juan de Fuca	328	9.91	95.38
Whidbey Basin	547	20.29	83.78
Total	3575	14.90	78.31

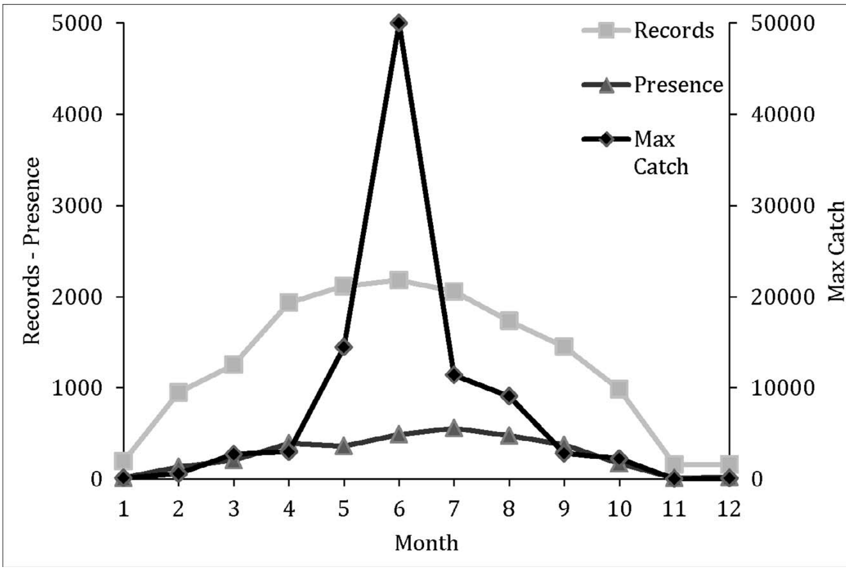

FIGURE 2. Sampling effort for Pacific Sand Lance by month, including the number of samples, the total number of records where Sand Lance were captured, and the largest number of Sand Lance caught represented as maximum catch per month.

that even without targeted sampling efforts, retrospective analysis of other capture data can be used to help describe the general distribution of an understudied and important species.

Average fork length measurements provided did not vary by month (Fig. 4). Although fish caught may underestimate smaller size classes overall, the shorter minimum fork lengths seen in April through July could represent annual recruits, and schools could therefore consist of different-age animals or different cohorts. The life-history characteristics of Sand Lance have been well documented in Cook Inlet, Alaska (Robards and others 1999b), where adults spawn between September and November and juveniles hatch on average 67 d later. In Puget Sound, however, Sand Lance spawn intertidally between November and February and egg development occurs in about 1 mo (Penttila 1995). Data on fork length of captured Sand Lance from Alaska and Washington are consistent, suggesting that the shorter minimum fork lengths seen between April and July in Puget Sound represent intertidally spawned juveniles from eggs hatched between December and March.

Low variability in fork length for individual samples suggests similar length classes are being caught in each net. Length-at-age classification for Sand Lance in Alaska found some separation between age classes (Robards and others 1999b), with decreasing separation between mean lengths after year 1. Similarities in length also could have been an artifact of sampling technique. Sand Lance fork-length data from Rhinoceros Auklet diet from 2006–2008 provided by Scott Pearson (Washington Department of Fish and Wildlife) were similar to net-capture data presented here. Sand Lance were collected from nesting Rhinoceros Auklets at Destruction, Protection, and Tatoosh Islands in July and August each year. Maximum fork length recorded in 1542 samples was 14.6 cm, while average fork lengths were 7.7, 10.6, and 9.3 cm for 2006, 2007, and 2008, respectively. These data illustrate the annual variation in Sand Lance size-class distribution.

In the North Pacific, adult Sand Lance reach a maximum fork length of 26 cm (Robards and others 1999b), with maturity occurring at between 12 to 15 cm. The largest individual specimen reported in Washington had a fork length of 19 cm, and only 6.5% of measured fish exceeded 12 cm. Without data on size at maturation in this region, it is difficult to say whether adult Sand Lance are smaller in Puget Sound than in the North Pacific, or that the majority of specimens captured were not adults. Size distributions in the present study varied by

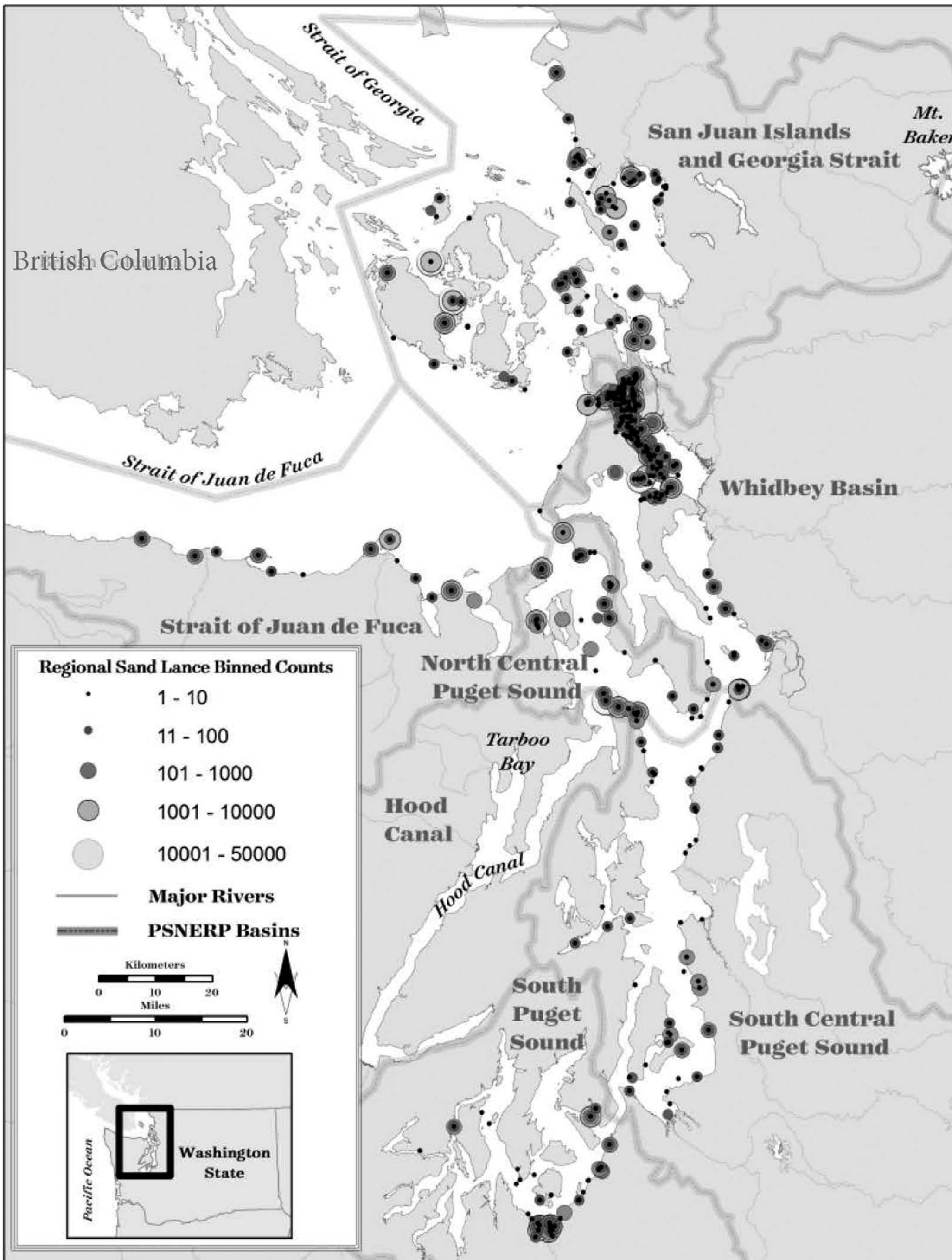

FIGURE 3. The number of Pacific Sand Lance per record, for each site. Sites where Sand Lance were not captured are not included. The number of fish per record are grouped into bins by logarithmic scale. Each bin denotes the size of the school of fish captured. Larger, lighter, gray dots indicate larger captures.

TABLE 3. Pacific Sand Lance fork length by watershed basin. Max represents the largest fish measured during the full sample period, min represents the smallest fish measured, and mean is based on all fish measured. Fork length data were available for only 4 of the 6 watershed basins sampled.

Watershed basin	Number of sites	Max (cm)	Min (cm)	Mean (cm)	Number of fish measured
North Central Puget Sound	67	15.3	3.3	7.45	700
South Central Puget Sound	91	18.5	1.7	7.79	941
South Puget Sound	111	19.0	2.3	8.99	855
Whidbey Basin	551	17.7	2.3	8.28	6760

region, with 28% of the fish in the South Puget Sound basin exceeding 12 cm and only 3% of fish in the North Central Puget Sound basin exceeding 12 cm. Fish in the North Central Puget Sound basin also tended to be smaller, with a maximum fork length of only 15.3 cm. It is possible that Sand Lance populations along the west coast of the United States differ from each other with respect to size at maturation as well as with reproductive timing, but confirmation of these apparent trends requires more intensive and directed sampling. No genetic data are available for Sand Lance from the inland waters of Washington.

Relative abundance data in the present study could provide information with respect to foraging patterns of Sand Lance predators. School (catch) sizes in our samples ranged from fewer than 10 to 100s and even 1000s of fish. The largest catches of Sand Lance in the study region occurred between May and August, with peak catches estimated at 16,000 and 50,000 fish recorded in the San Juan Archipelago in June 1976 and 2005, respectively. Work conducted in Alaska also showed increased total beach seine catch of Sand Lance as well as highest percent frequency of occurrence in summer (Johnson and others 2008). Seasonal abundance has important biological implications. In a 2-y study of Harbor Seal (*Phoca vitulina*) diet in the San Juan Islands (Lance and others 2012), the frequency of occurrence of Sand Lance changed seasonally, by year, and by location, occurring in seal diet more frequently in spring than in summer-fall, occurring more in 2008 than in 2005, 2006 and 2007, and appearing most often in the San Juan Islands. Abundance of Sand Lance in Marbled Murrelet diet varies seasonally, with fewer Sand Lance in the winter diet (Burkett 1995). Reduced occurrence in winter could reflect an absolute reduction in Sand Lance

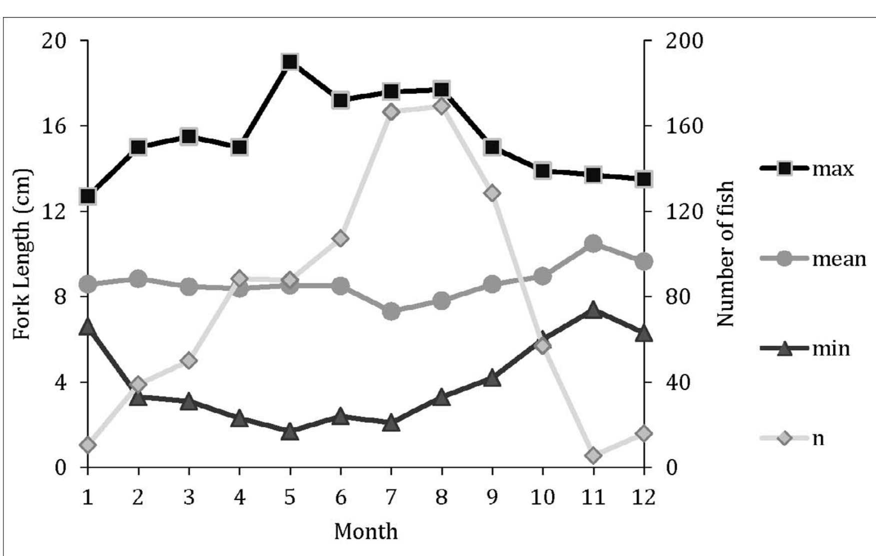

FIGURE 4. Fork length of Pacific Sand Lance by month.

availability in winter, fewer large schools of fish, or an increase in the relative abundance or distribution of another more preferred prey fish. Fresh (1979) showed that Sand Lance caught in the nearshore were primarily larval and juvenile fish, and were mostly absent from fall and winter records. In sum, available data suggest that reduced predation on Sand Lance in winter by some predatory species is related to a decrease in abundance of large schools of Sand Lance. Such patterns could have implications regarding critical prey availability for these and other ecologically vulnerable predator species, but more research is needed to ferret out the mechanisms or life-history traits driving patterns of prey abundance and predation.

The records we reviewed focused on nearshore, shallow regions, but Pacific Sand Lance are distributed across other habitats, providing additional evidence for their potential value as a food source for predatory species. Sand Lance also occur in deep water (>30 m) on sand wave fields in the San Juan Channel (Blaine 2006; Gary Greene, Tombolo Institute, Orcas Island, WA, pers. comm.). Blaine (2006) collected fish with a Van Veen benthic grab during November, a method not used in surveys discussed here. Local commercial fishermen and divers have observed Sand Lance at other deep-water sites in the inland waters of Washington, often at depths greater than 30 m (Jeff June, Natural Resources Consultants, Seattle, WA, pers. comm.). Blaine (2006) recorded a mean fork length of 7.9 cm for fish captured in sand wave fields and only 1 specimen >10 cm, consistent with the results of beach seine data with an average fork length of 8 to 10 cm and few fish larger than 12 cm. One apparent difference is the occurrence of smaller fish in deeper water. Blaine (2006) found a minimum fork length of fish captured in sand wave fields of 6.5 cm, whereas fish captured in beach seines were as small as 1.7 cm. For small-scale depth comparisons conducted in the nearshore, on the west coast of southern Vancouver Island, Haynes and others (2007) found 0-year class individuals in deeper water and 1-year class individuals in shallow water. More work is needed to determine if behavioral and habitat preferences exist for Sand Lance in the inland waters of Washington.

Lacking a better understanding of the basic biology of this species, it is impossible to gauge the potential anthropogenic or natural impacts on regional food webs. This study demonstrates that Sand Lance are present throughout the inland waters of Washington, which is consistent with the hypothesis that they are important drivers of local marine food webs.

Numerous knowledge gaps exist about this ecologically important fish in the inland waters of Washington, including basic knowledge about the status of populations and subpopulations. Future studies should focus on subtidal habitat associations such as with deep-water sand wave fields, stock structure, spatial or regional distribution, habitat use at separate life-history stages, size at maturity, recruitment strength, vertical migration in the water column, and gene flow and connectivity between possible subpopulations. This information is important for state and federal managers responsible for implementing conservation and fisheries management plans.

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